1

NASA-CR-135249

NASA CR-135249

QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

Under-the-Wing (UTW) Engine Boilerplate Nacelle Test Report

VOLUME I

Summary Report

DECEMBER 1977

by

Advanced Engineering and Technology Programs Department

GENERAL ELECTRIC COMPANY

Prepared For

National Aeronautics and Space Administration

NASA-Lewis Research Center

NAS3-18021

1. Report No. NASA CR-135249	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle QCSEE UNDER-THE-WING (UTW) ENGINE BOILERPLATE NACELLE TEST REPORT - VOLUME I, SUMMARY REPORT		5. Report Date December 31, 1977
		6. Performing Organization Code
7. Author(s) Advanced Engineering and Technology Programs Department Group Engineering Division		8. Performing Organization Report No. R77AEG212-1
		10. Work Unit No.
9. Performing Organization Name and Address General Electric Company Aircraft Engine Group Cincinnati, Ohio 45215		11. Contract or Grant No. NAS3-18021
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Experimental Report, Project Manager, C.C. Ciepluch, QCSEE Project Office
Technical Adviser, N.E. Samanich, NASA-Lewis Research Center, Cleveland, Ohio 44135

16. Abstract

The Quiet Clean Short-Haul Experimental Engine (QCSEE) Program includes the design and testing of high bypass geared turbofan engines with nacelles forming the propulsion systems for short-haul passenger aircraft. These flight systems contain the technology required for externally blown-flap-type aircraft for introduction into passenger service in the 1980's.

This report covers the initial phase of testing of the Under-the-Wing (UTW) engine and boilerplate nacelle components. The report consists of three volumes and an appendix as follows:

Volume I	- Summary Report	CR-135249
Volume II	- Aerodynamics and Performance	CR-135250
Volume III	- Mechanical Performance	CR-135251
Appendix	- Detailed Engine Performance	For Government Use Only

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Aircraft Propulsion Power Integrated Engine/Nacelle Structure Variable-Pitch Fans Propulsion System Testing	An Early Domestic Dissemination Report

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED	64	

* For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA-C-168 (Rev. 6-71)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 SUMMARY

The QCSEE UTW Propulsion System was tested at General Electric's Peebles, Ohio Outdoor Test Site IV-D during the fourth quarter of 1976. Approximately 47 hours of engine operation were completed, including mechanical and controls checkout, aeroperformance mapping with a bellmouth inlet and hardwall boilerplate nacelle, performance rating checks with a high Mach number inlet, and initial reverse thrust testing.

During the reverse thrust test, the fan exhaust nozzle support ring attachment failed, allowing one nozzle flap to be ingested by the engine. This failure resulted in premature termination of the test. The engine will be repaired and rebuilt to resume testing in September 1977 with the composite nacelle.

Engine performance in the forward mode was close to predictions, meeting the uninstalled thrust and sfc goals and the installed thrust goal. Reverse thrust appeared to be lower than predicted, although the test was terminated before the optimum reverse thrust fan blade angle was tested. Performance of the variable pitch fan in the forward operating mode agreed well with predictions based on the scale model simulator, meeting airflow, pressure rise, and efficiency objectives over the tested range of speeds and blade angles.

Mechanical operation of the engine was generally satisfactory after correction of initial oil leaks from the composite fan frame sump. The composite fan blades indicated a sensitivity to crosswinds, particularly in the region of first flex - 2/rev crossover. Further development is required to make the blades fully operational. The harmonic drive variable-pitch actuation system functioned satisfactorily at reduced speeds, but the blades could not be moved at maximum fan speed. The main reduction gear indicated slightly lower than objective efficiency levels, with otherwise satisfactory performance. The digital control provided stable, accurate control of fan speed, fan blade angle, and exhaust nozzle area in the manual mode of operation. Testing was not attempted in the automatic mode.

In consideration of the many elements of new technology represented by the components of the UTW engine, the initial test series was quite successful. Further testing planned for the next buildup can be expected to validate most of the design concepts for future use.

2.0 INTRODUCTION

The General Electric Company is currently engaged in the Quiet, Clean, Short-Haul Experimental Engine Program (QCSEE) under Contract NAS3-18021 to the NASA Lewis Research Center. The under-the-wing (UTW) experimental engine was designed and built under the program to develop and demonstrate technology applicable to engines for future commercial short-haul turbofan aircraft.

The initial buildup of the UTW engine and boilerplate nacelle was tested at General Electric's Peebles, Ohio Outdoor Test Site IV-D during the period from September 2 through December 17, 1976. Initial testing included a mechanical and systems checkout with hardwall acoustic panels and a bellmouth inlet. Performance data were then taken over a range of speeds, exhaust nozzle areas, and fan blade angles. This phase of testing provided data in the range of takeoff and approach operating conditions to explore "uninstalled" performance with minimal loss of ram recovery. In addition, fan performance characteristics were mapped over a limited range of blade settings.

The inlet was then changed to the boilerplate high Mach number design to investigate installed performance with real ram recovery losses. Points were repeated at takeoff and approach operating conditions.

Initial reverse thrust testing was attempted by transitioning the blades to the reverse setting (through stall pitch) while motoring on the starter. The engine was then fired in the reverse mode and operated to higher speeds. During this phase of testing, the exhaust nozzle support ring failed, allowing one nozzle flap and associated hardware to be ingested by the engine. This failure resulted in a premature conclusion of the test before much of the desired reverse mode and acoustic data could be acquired.

This volume of the propulsion system test report includes a description of the equipment tested and the test facility, an instrumentation summary, a chronological history of the test, and a summary of results.

3.0 DESCRIPTION OF EQUIPMENT TESTED

The under-the-wing propulsion system (Figure 1 and Reference 1) included a variable pitch, high bypass ratio, gear driven fan and a YF101 core engine and low pressure turbine. The fan frame was an all-composite structure forming a section of the nacelle wall. The aft fan duct and core cowl were boilerplate components having interchangeable hardwall and acoustic suppression panels. The fan exhaust nozzle was a four-flap variable area composite assembly. The core exhaust nozzle consisted of a shroud and plug with both hardwall and acoustically treated metal parts available. The engine was tested with two inlets; a bellmouth design for performance calibration and an accelerating inlet designed to produce 0.79 throat Mach number to suppress forward-radiated fan noise. A more detailed description of these components follows. A cross section drawing of the propulsion system is provided in Figure 2.

3.1 FAN ROTOR ASSEMBLY

The UTW engine has 18 composite fan blades mounted in trunnions to allow the fan blade pitch angle to be changed by rotating the trunnions. The blade and trunnion centrifugal loads are carried by single-row ball, grease lubricated bearings. Secondary and vibratory loads from the trunnions are carried by dry thrust and journal bearings located in the periphery of the machined titanium disk.

The variable-pitch actuation mechanism, developed by Hamilton Standard Division of United Aircraft Corporation, includes a Beta Regulator (electrohydraulic servovalve, hydraulic motors, and two linear variable differential transformers), flexible drive cable, differential gears, spring-type no-back, harmonic drive, and cam and blade actuation arms. The servovalve directs high pressure oil to the hydraulic motor which rotates the flexible cable, sending a pitch change command through the differential gear set to the no-back. Motion of the no-back is sent through the harmonic and cam track to the lever arms which move the blades.

3.2 MAIN REDUCTION GEAR

The main reduction gearset for the UTW engine is an epicyclic star configuration developed by Curtiss-Wright Corporation. The low pressure turbine rotor is splined to a sun gear which drives a ring gear through a set of six star gears. The star gears are mounted on tandem, spherical roller bearings which are mounted on a fixed carrier. Lubrication requirements for the reduction gear vary between approximately 1134 cc/s (18 gpm) at idle to approximately 1512 cc/s (24 gpm) at takeoff. The gear ratio is 2.4648 and both the input and output are flexibly mounted to prevent engine deflections from influencing the gear operation.

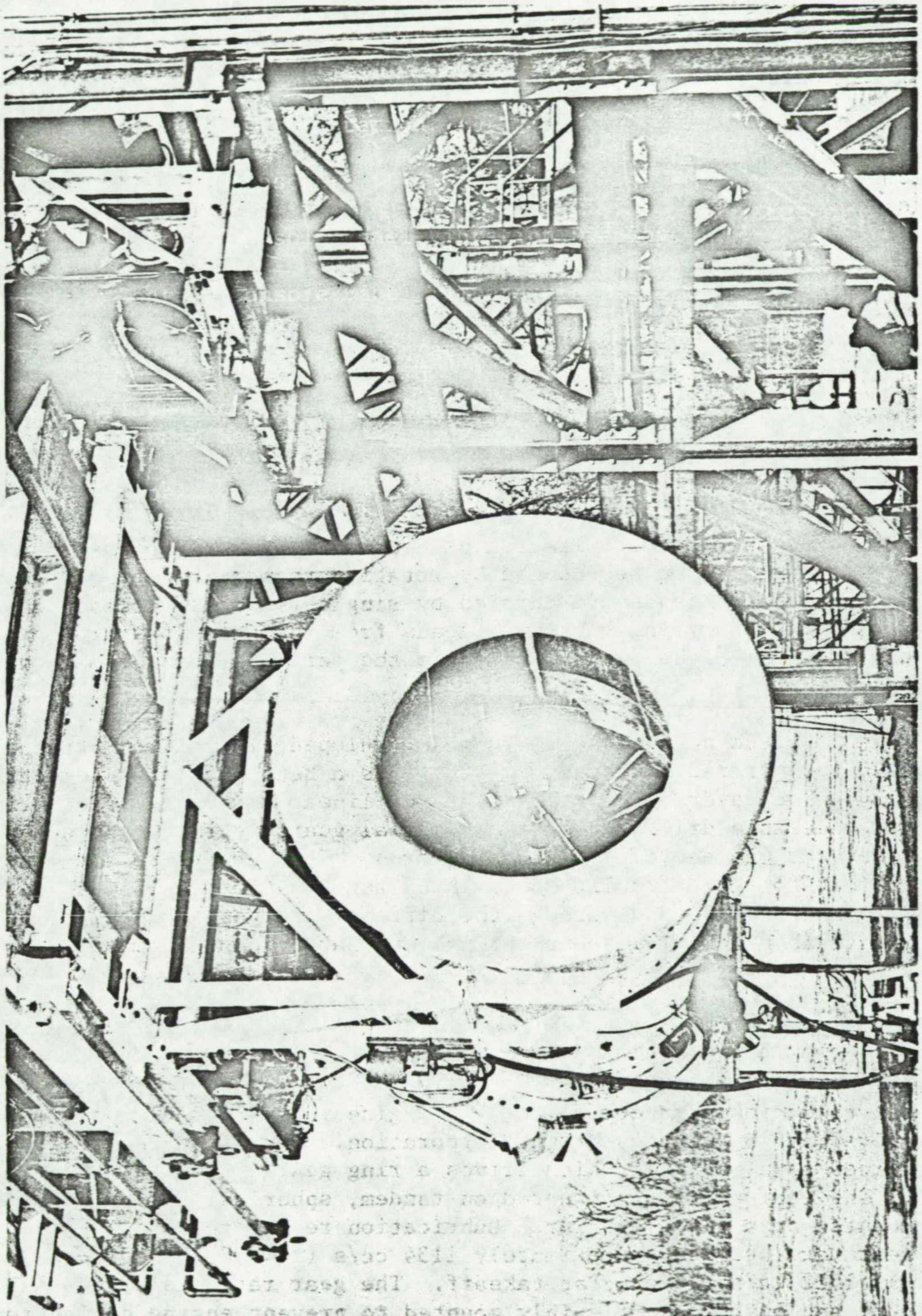

Figure 1. UTW Experimental Propulsion System Test Installation.

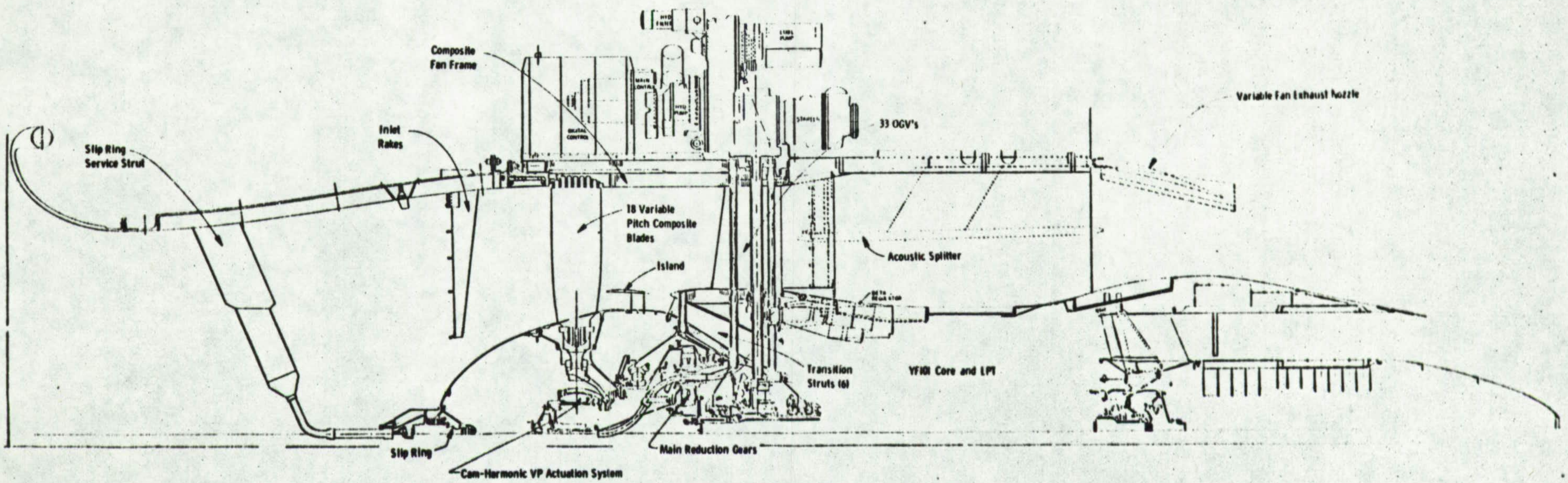

Figure 2. UTW Propulsion System Cross Section.

3.3 FAN FRAME

The fan frame is an all-composite static structure formed from integration of several separate structures, as shown in Figure 3. The outer casing of the frame combines the function of the nacelle with the frame outer shell. This casing provides part of the external nacelle surface as well as the internal fan flowpath. Fan blade tip treatment is provided by a grooved structure integrated into the forward portion of the outer casing. Containment of failed composite airfoils is provided by a felted Kevlar band in the outer casing. Positioning of the fan and core engine relative to the outer casing is provided by 33 vanes which also serve as the fan-bypass stator vanes. The hub of the frame is connected to the frame splitter through six equally spaced struts. The inner shell of the outer casing, the bypass duct and core duct surfaces of the frame splitter, and the pressure faces of the bypass vanes are perforated to provide acoustic suppression within the frame structure. The forward end of the compressor attaches to the rear of the frame at the exit of the frame inner airflow path. The outer cowl doors attach by a tongue-and-groove arrangement to the outer casing at the rear of the frame. The core cowl doors attach in a similar manner to the forward end of the casing by 16 rotary latches. The frame also provides the major support point for the engine through a uniball and two thrust mounts located at the top of the core cowl.

Flow turning of the fan flow into the core is provided by an independent set of metallic outlet guide vanes attached to the forward flange of the frame hub. The island splitter is formed from sheet metal with the stator vanes penetrating and brazed to the skins. The stator vanes are supported at the hub through brazed joints into an inner casing that is bolted to the fan frame.

3.4 CORE ENGINE

The QCSEE UTW engine utilized the YF101 core with modifications described as follows.

The nine-stage, highly loaded compressor is designed for 12.5 pressure ratio at 27.2 kg/s (60 lb/sec) corrected flow. The IGV and Stage 1-3 vanes are variable to control stall margin and performance at part-speed conditions. The stator schedule was modified to high-flow the compressor above 83% corrected speed and to provide additional stall margin in the starting range. The schedule change necessitated minor modifications to the actuation linkage, and also a flex-cable feedback was used in place of the F101 splined shaft system.

The YF101 first-stage compressor blades have leading and trailing edges "cropped" at the tip. The QCSEE engines utilized the full-span PV airfoil mounted on the PFRT dovetail. The mechanical rotor speed limit was set at 14,050 rpm to ensure adequate vibratory margin.

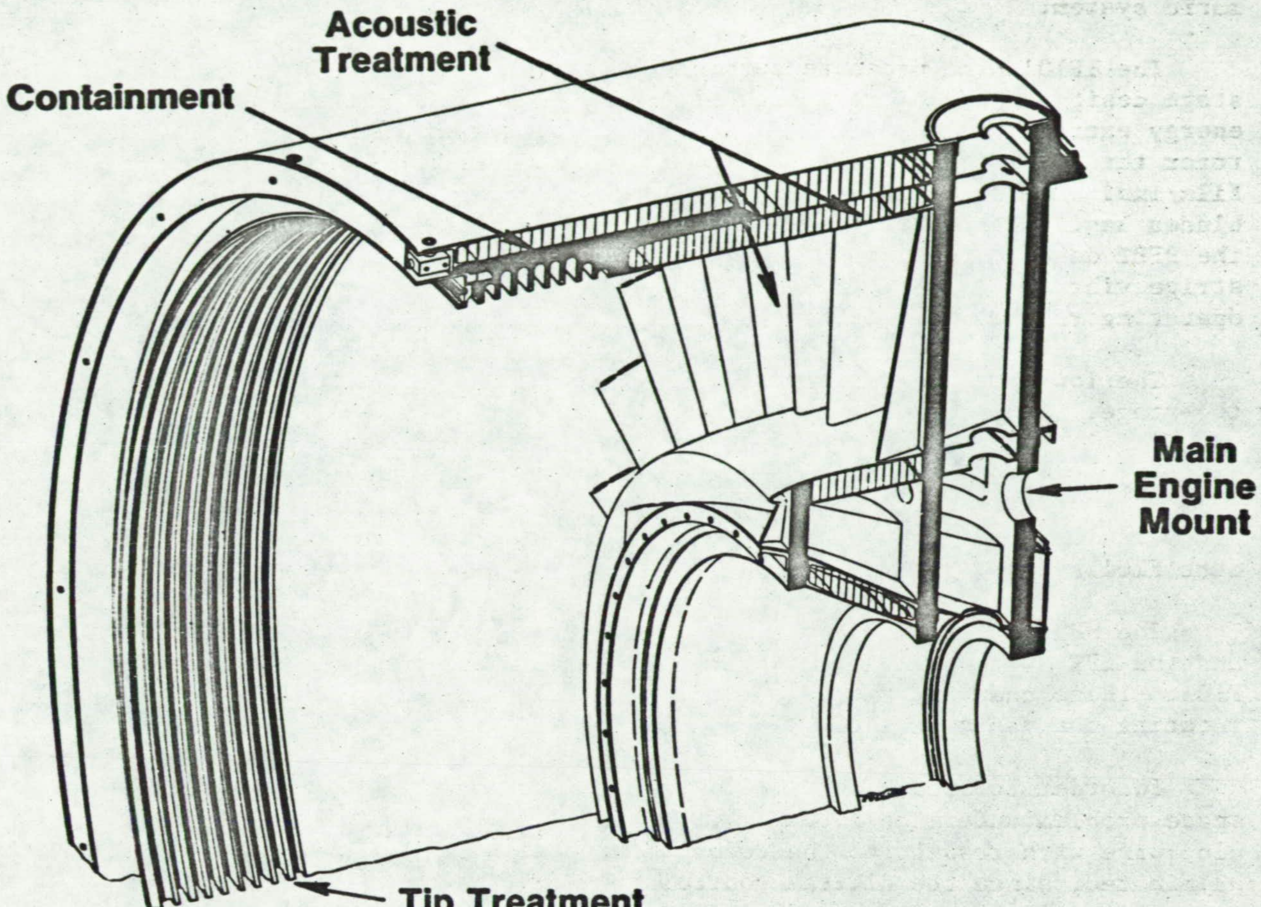

Figure 3. Composite Fan Frame.

The UTW engine used the PV central injector dome combustor to achieve lower emission levels than the PFRT design as demonstrated by rig testing. A single manually-operated ignitor was used in place of the F101 dual automatic system.

The YF101 high pressure turbine used in the QCSEE engine is a single-stage design utilizing very high tip speed to achieve the required level of energy extraction in a single stage. Cooling air is introduced into the rotor through an inducer located inboard of the nozzle vanes. The vanes are film/impingement cooled by CDP air. The UTW engine used F101 "warm bridge" blades having demonstrated high temperature and cyclic life advantages over the PFRT design. The blades were frequency screened to ensure that the two-stripe vibratory mode is resonant with vane passage frequency well above the operating range. HPT shrouds were of the improved PV design.

The low pressure turbine of the UTW engine was identical to the YF101 two-stage, tip-shrouded design except that the PV second-stage blade was used. This blade is slightly decambered to reduce the exit swirl resulting from increased energy extraction. The turbine frame vane/struts were extended 2.54 cm (1 in.) forward to accept the greater turbine exit swirl. The frame was also modified to provide engine mounts not required in the long duct F101.

The HPT diaphragm area was increased to provide 5% larger flow function, and the LPT area reduced to provide 5% smaller flow function than in the F101. These changes, required for cycle matching, were accomplished by rotating the vanes slightly in the bands before brazing.

In order to locate the ignitor plug in the pylon region and eliminate a space problem under the core cowl, the aft end of the engine was rotated 120° clockwise with respect to the compressor. The F101 infrared pyrometer was eliminated, since the digital control provided the capability to instantaneously calculate T_{41} based on measured P_{S3} and T_{T3}.

Because of the reduction gear system in the LP power train, the fan rotor thrust could not be balanced against the LPT rotor thrust. A balance piston was therefore added to the rear of the LPT rotor. CDP air was used to balance the turbine rotor thrust. Fan rotor thrust was carried by a high-capacity ball bearing in the fan frame.

3.5 DIGITAL CONTROL

The digital electronic control manipulates variables in response to commands representing those which would be received from an aircraft propulsion system. The system includes an F101 hydromechanical control through which the digital control maintains primary control of fuel flow. The fuel-operated servomechanisms in the hydromechanical control serve primarily as backup fuel controlling elements and limits, although they are the primary controlling elements for the core compressor stator actuators. Fan blade

pitch angle and fan exhaust nozzle area are both controlled by the digital control, which furnishes electrical signals to electrohydraulic servovalves.

The commands to the digital control are introduced through the control room elements consisting of an interconnect unit, operator panel, and engineering panel. They provide means for the engine operator to introduce commands, to switch between available operating modes, to adjust various control constants, and to monitor control and engine data. In addition to these digital commands from the control room, the system also receives a mechanical input in the form of a power lever angle (PLA) transmitted to the hydromechanical control. This serves as an input to the backup governor and operates a positive fuel shutoff valve in the control.

The following control and engine variables are sensed by the control system:

- Core speed
- Low pressure turbine speed
- Core inlet temperature
- Core stator position
- Compressor discharge temperature
- Metering valve position
- Engine inlet static pressure
- Fan inlet temperature
- Free-stream total pressure
- Fan pitch angle
- Fan nozzle position
- Compressor discharge pressure
- Power lever angle
- Power demand

The control has several manual and automatic modes of operation. In the manual mode, the operator commands fuel flow, blade angle, and exhaust nozzle area. In the fully automatic mode, the operator commands percent rated thrust, and the digital control varies fuel flow to hold engine pressure ratio (as a thrust parameter), varies fan blade angle to hold fan speed, and varies exhaust nozzle area to hold inlet Mach number. In all modes, the control provides accel and decel limits, overspeed, and overtemperature limits.

3.6 FAN NOZZLE

The fan exhaust nozzle (which acts as an inlet during reverse operation) consists of four composite flaps. These flaps are driven in a closed loop system to provide a fully-modulating exhaust nozzle. Six hydraulic actuators, three in each rear cowling half, are arranged circumferentially to power the flaps. Flow control is by an electrohydraulic servovalve. Synchronization in each cowl half is provided by the common center mounted actuator in each half and by the structural rigidity of the flap nozzle

flanges. Cross-synchronization between right and left halves is provided by a rotary shaft coupling between two opposite actuators.

3.7 CORE NOZZLE

The core nozzle is a fixed area nozzle with a separate but interchangeable outer cowl that is bolted to the aft cone and can be trimmed for nozzle area adjustment. A radial service strut is located at the bottom centerline of the core exhaust nozzle to provide aerodynamic fairing over the oil inlet, oil drain, seal drain, and balance piston air lines that pass through the core nozzle to the sump. The strut is designed so that the strut and service lines need not be disassembled to remove the centerbody or outer duct. Both the outer nozzle and centerbody have been fabricated in both hardwall and acoustically treated configurations.

3.8 ACCESSORY DRIVE SYSTEM

Engine accessory power is extracted from the core engine shaft through right angle bevel gearing (two F101 inlet gearboxes). The power is transmitted through radial drive shafting to a top-mounted accessory gearbox and to a scavenge pump mounted in the core cavity area on the bottom vertical centerline. Mounted on, and driven by, the accessory gearbox are the fuel pump and control, lubrication supply pump, hydraulic pump, control alternator, and starter drive pad. The radial drive shaft between the internal bevel gear and the accessory gearbox has a central support bearing to eliminate shaft critical speed problems. The shaft between the internal bevel gear and the bottom mounted scavenge pump does not require a central support bearing because of its short overall length.

3.9 INLET

Testing of the UTW engine required two boilerplate inlet configurations. The NASA Quiet Engine "C" bellmouth inlet was utilized for aerodynamic engine mapping. A hybrid configuration featuring elevated throat Mach number and multiple acoustic suppression design capability was employed for the aeromechanical evaluations. All inlets were mechanically decoupled from the engine to prevent overload of the composite fan frame flange due to excessive motion/vibration. An air seal is provided by an open-cell foam, Scott-Felt, bonded to one-half of the flange and pressed against the other. An acoustic seal is provided by lead foil in a vinyl cover. The two seals aerodynamically and acoustically simulate the hard-joint condition of the final composite propulsion system assembly.

3.10 FAN COWLING

The UTW fan bypass duct is a fabricated aluminum sheet and stringer assembly consisting of two semicircular door structures that provide the attachment capability for an interchangeable set of acoustic treatment and one matched set of hardwall panels. Core cowl access is accommodated by the hinged door construction of the outer ducting. The outer fan doors are decoupled from the fan frame (to prevent the transmission of excessive nacelle weight to the fan frame), and the primary structural attachment to the pylon is made through two heavy duty, piano-type hinges located at the top edge of the door assemblies. All forward and aft fan cowl loads are transmitted through the hinge to the facility structure.

3.11 ACOUSTIC SPLITTER

The aft duct acoustic splitter assembly is a fabricated component consisting of aluminum sheet metal skins, machined rings, and honeycomb core resulting in a double-sandwich construction. The leading and trailing edge close-outs are machined aluminum rings. The assembly consists of two semicircular structures supported from the fan duct doors by six stainless steel airfoil-shaped struts. Silicon seals have been applied to the ends of the splitter halves to dampen potential vibratory movement during engine testing. The splitter is designed to be removable. Separate filler pieces which duplicate the strut feet can be inserted in the fan doors during engine operation without the splitter.

3.12 CORE COWL

The UTW core cowl embodies the same design approach used for the fan duct. It is a stainless steel fabricated structure that supports interchangeable acoustic or hardwall panels. It has a forward interface (Marman-type joint) with the fan frame and a rear interfacing slip joint with the core nozzle. Access to the compressor and turbine is provided by hinged-door construction. The core doors and skirt system are temporarily supported by the pylon through a set of pins when opened. The core cowl employs shop air for cooling. This air is ducted around the engine and released inside the core cowl. It exhausts upward through the pylon.

3.13 ENGINE MOUNTS

All boilerplate nacelle hardware is supported from the test stand. Normal engine thrust and other operating loads are carried through the main engine mounts to the test stand. Thrust, vertical, and side loads are reacted at the front mount: vertical, side, and torque loads are taken by a three-link arrangement at the rear mount plane on the outer shell of the turbine frame.

3.14 HYDRAULIC SUPPLY SYSTEM

The hydraulic supply system provides hydraulic power to the fan duct nozzle (A18) actuators and the fan blade actuation system. A pressure compensated hydraulic piston pump is driven by the accessory gearbox and provides varying flow output at constant pressure to servovalves which are part of the fan duct nozzle and variable-pitch systems. Pump output flow is determined by the demand from the servovalves, varying from zero at holding condition to maximum during the engine thrust reversal transient. The hydraulic system receives and uses the same oil as the engine lubrication system. Once the hydraulic system is filled, however, it functions very nearly as an independent closed system. A 10-micron filter provides contaminant protection at the servovalve inlet.

3.15 FUEL SYSTEM

The UTW fuel delivery system is composed of F101 engine main fuel system components. The system includes the hydromechanical control (metering section), main fuel pump, and fuel filter.

3.16 IGNITION SYSTEM

The ignition system consists of an ignition exciter box, ignition lead and spark igniter located in the pylon. These components are of CFM56 design. The system will permit continuous sparking with a stored exciter energy of 14.5 - 16.0 joules for a delivered nominal spark energy of 2 joules at a nominal rate of 2 sparks/second. The ignition system is powered by a facility supply which provides 115 volt - 400 Hz power through permanent facility wiring to the engine-mounted ignition box. A momentary contact pushbutton on the Engine Control Module (ECM) is used to turn on the ignition system. The pushbutton legend, labeled "ON," is illuminated while the pushbutton is held in the depressed position and goes off when the pushbutton is released.

3.17 STARTING SYSTEM

An air turbine starter and control valve are mounted on the accessory gearbox. The facility system provides a regulated flow of filtered air to the engine starter for engine motoring operations. Controls are located on the ECM in the control room. The system has been designed to deliver up to 2.26 kg/s (5 lb/sec) of shop air at 41.4 N/cm^2 (60 psig).

In the normal mode of operation, the air-start system can be operated only when the engine speed is below the minimum engagement speed set on the starter protection module, and when the main facility fuel valve is open. An emergency mode of operation bypasses the engine speed and fuel valve interlocks and permits the cell operator to motor the engine in any emergency,

such as to blow out an internal fire or to motor the engine after a flameout until it has cooled sufficiently for a safe shutdown.

3.18 SLIPRING

A 100-point, no-leak, minislipring was used to transmit blade and ring gear strain signals. Leadout and cooling from lines were routed through a slipring service strut mounted in the inlet. The strut also acts as an antirotational device for the slipring.

3.19 SLAVE LUBRICATION PACKAGE

The QCSEE slave lube system (Figure 4) is an off-engine-mounted package that conditions and stores the MIL-L-23699 lube oil. Flexible hoses are used to connect the package to the engine components. All fluid connections to the package are located on a common bulkhead on the base of the package. Electrical connections for oil level and cooling water flow measurements are made directly to connectors on the measuring devices. A leak-tight drip pan with a drain connection is provided in the base of the package. The package has been designed to receive and condition up to 9450 cm^3/s (150 gpm) of aerated scavenge return oil at temperatures up to 450 K (350° F) and to deliver up to 3150 cm^3/s (50 gpm) of cooled, filtered, and deaerated oil to the engine lube pump at 339 K (150° F) and 17.2 N/cm^2 (25 psia). Oil tanks on the package have a combined storage capacity of 0.076 m^3 (20 gallons). The oil cooling system rated capacity is 528,000 J/s (30,000 Btu/min) using 6300 cm^3/s (100 gpm) of water.

Principal components of QCSEE slave lube package are the main oil tank, auxiliary oil tank, scavenge oil filter, water-oil heat exchanger, water filter, water flowmeter, and waterflow control valve.

Hot, aerated scavenge return oil is pumped to the package by the engine-mounted scavenge pump. The scavenge oil first flows through the scavenge oil filter where particles, 10 micron and larger, are filtered out of the oil. If the retention capacity of the filter element is exceeded, a bypass valve opens at 34.5 $N/cm^2 \pm 3.5$ N/cm^2 (50 psid $\pm$ 5 psi) to maintain lube flow. Before the bypass condition is reached, however, a "Lube Scavenge Hi ΔP" warning is given to the test operator.

Bypass indication is also provided on the filter. At 34.5 $N/cm^2 \pm 3.5$ N/cm^2 (40 psid $\pm$ 5 psi), a red button "pops up" and becomes visible in the sight-glass atop the filter, thus providing visual indication at the slave lube package that the filter is about to bypass or is bypassing depending on the actual pressure drop across the filter. The red button will remain in the "up" position until the sight-glass is removed and the button is manually depressed. Pressure taps are provided upstream and downstream of the scavenge oil filter to monitor the pressure drop across the filter.

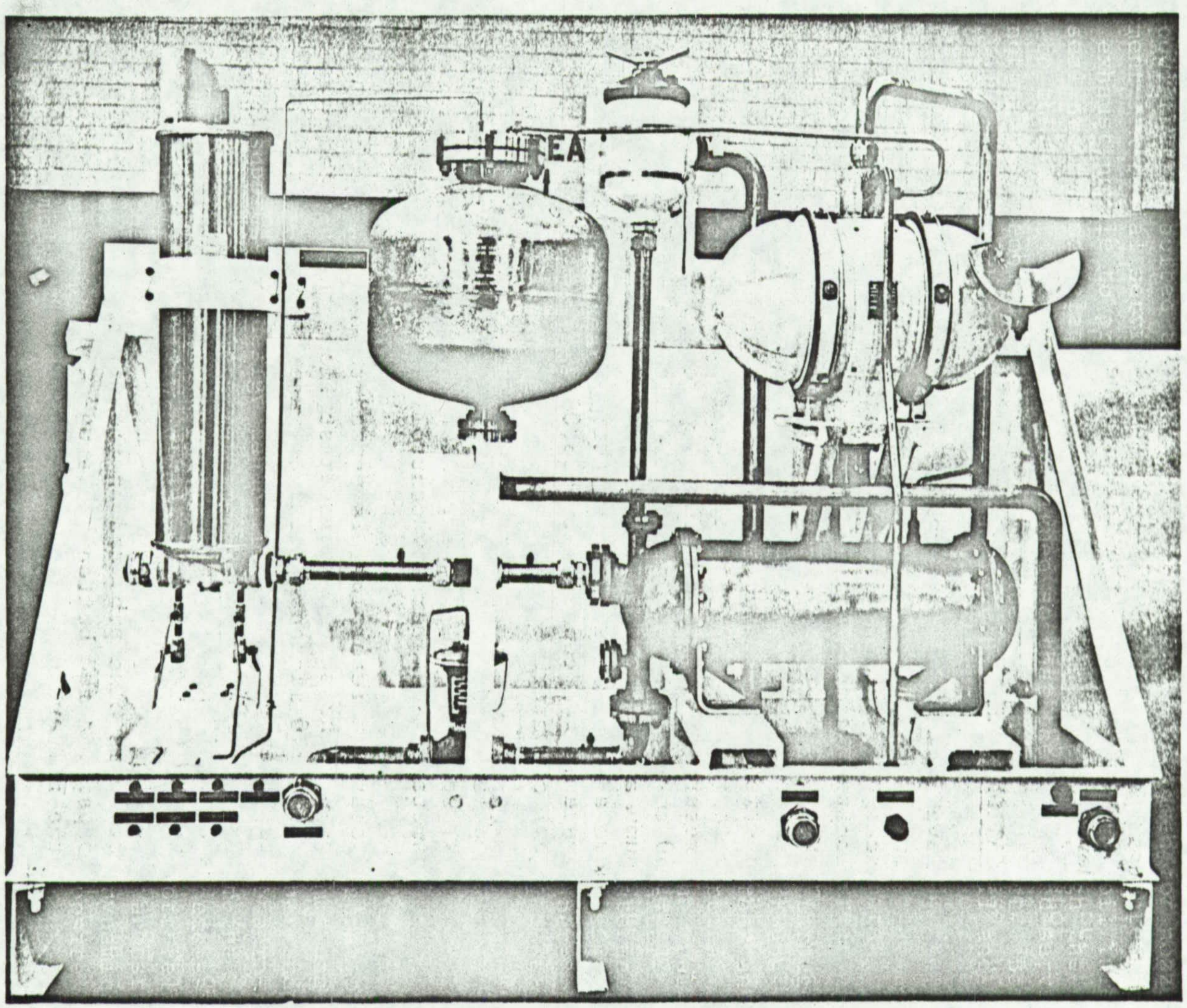

Figure 4. QCSEE Slave Lube System.

The hot, aerated, and filtered oil then passes through the water-oil heat exchanger where it is cooled to 339 K (150° F) by controlling the water-flow through the heat exchanger.

From the heat exchanger, oil is routed to the scavenge return port on the main oil tank. On entering the main oil tank, the oil is deaerated by flowing through the vortex generator located in the tank inlet. The cooled, filtered, and deaerated oil drains into the tank where it mixes with the oil reserve in the tank, which is ten gallons when the tank is full. The auxiliary oil tank provides an additional 0.0379 m^3 (10 gal) of oil reserve capacity which is required to handle the engine scavenge system gulping requirements. It also provides for return of the A18 actuator seal-drains' oil through a port in the top flange. A common vent line between the main and auxiliary tanks provides for equalization of pressure in the two tanks so that the same oil level is maintained in both tanks. Clean, cooled, and deaerated lube oil is drawn through a combined discharge line from both tanks as required to supply oil to the engine-mounted lube pump.

4.0 DESCRIPTION OF TEST FACILITY

The QCSEE UTW engine was tested at General Electric's Peebles, Ohio remote test site (Figure 5). Engine installation was at Site IV, Pad D, aeroacoustic test facility. This test facility is located 80 miles due east of the General Electric, Evendale, Ohio Plant and is readily accessible by road or air.

The facility provided for fuel, cooling water, facility and instrument air, fire protection, and thrust measurement systems. An "off engine" lube system was designed and constructed for the QCSEE Program and installed on the test stand (Figure 4).

Fuel is stored at a remote fuel farm (Figure 6) and is pumped through underground lines to the test pad where it passes through a 10-micron filter before going to the engine. During engine test, the fuel stopcock is operated from the facility control room. JP-5 fuel was used on QCSEE UTW engine test.

Water for cooling is pumped from a reservoir located on the test facility grounds. The water is filtered prior to entering the test pad manifold. Cooling water was used in the "off engine" lube system heat exchanger and was remotely controlled from the Pad D control console. Waterflow was measured by use of a turbine flowmeter and was displayed and recorded during engine test. Adjustments to the waterflow were required during engine test to maintain a constant oil temperature in the lube system supply. Waterflow was varied between 0 and 0.568 m^3 (0 and 150 gal) per minute.

The facility air supply is a regulated and filtered system. Facility air was used for the air-start system, under cowl cooling, aft-sump cooling, and engine eductors. Each of these systems was individually controlled and remotely operated from the control console during engine test. Instrument air is a dried air system used on the electropneumatic valve controllers, digital control, and slipring system. Engine eductors were added during test of the QCSEE UTW engine.

The facility has both water-sprinkler and inert-gas fire protection systems. Sprinkler heads are located in the facility structure while the inert gas system is connected for use through the engine air-cooling system. Both systems can be operated from the test pad or the control room. In addition to these systems, dry-chemical fire extinguishers are located at the pad for use by Peebles test personnel who have been instructed in their use.

Engine thrust was measured using a three-bridge 133,000 N (30,000 lb) load cell. The thrust system was calibrated for forward and reverse thrust testing. One of the load cell bridges would not calibrate properly and was not used for performance data.

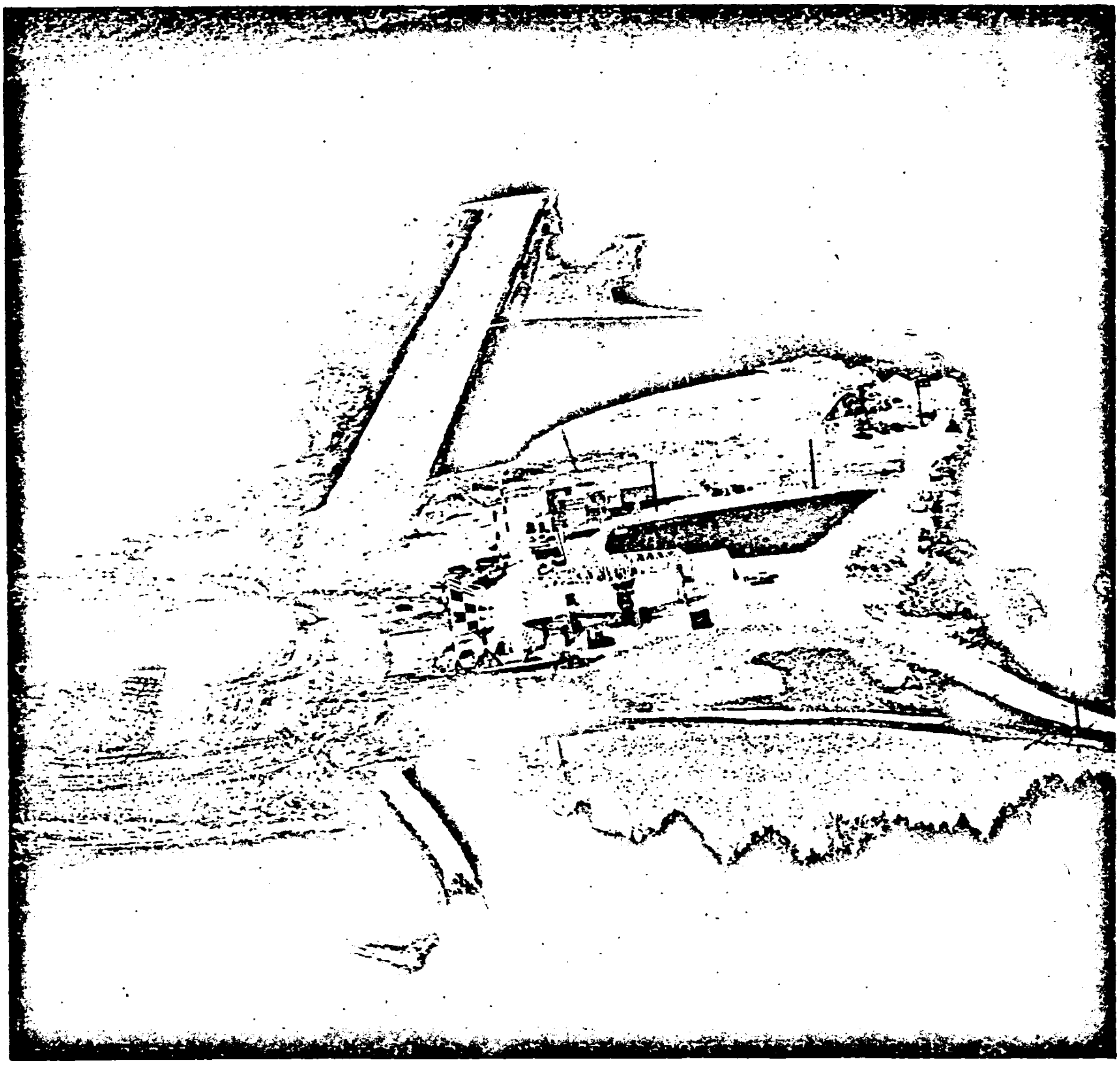

Figure 5. Peebles, Ohio Test Site IV.

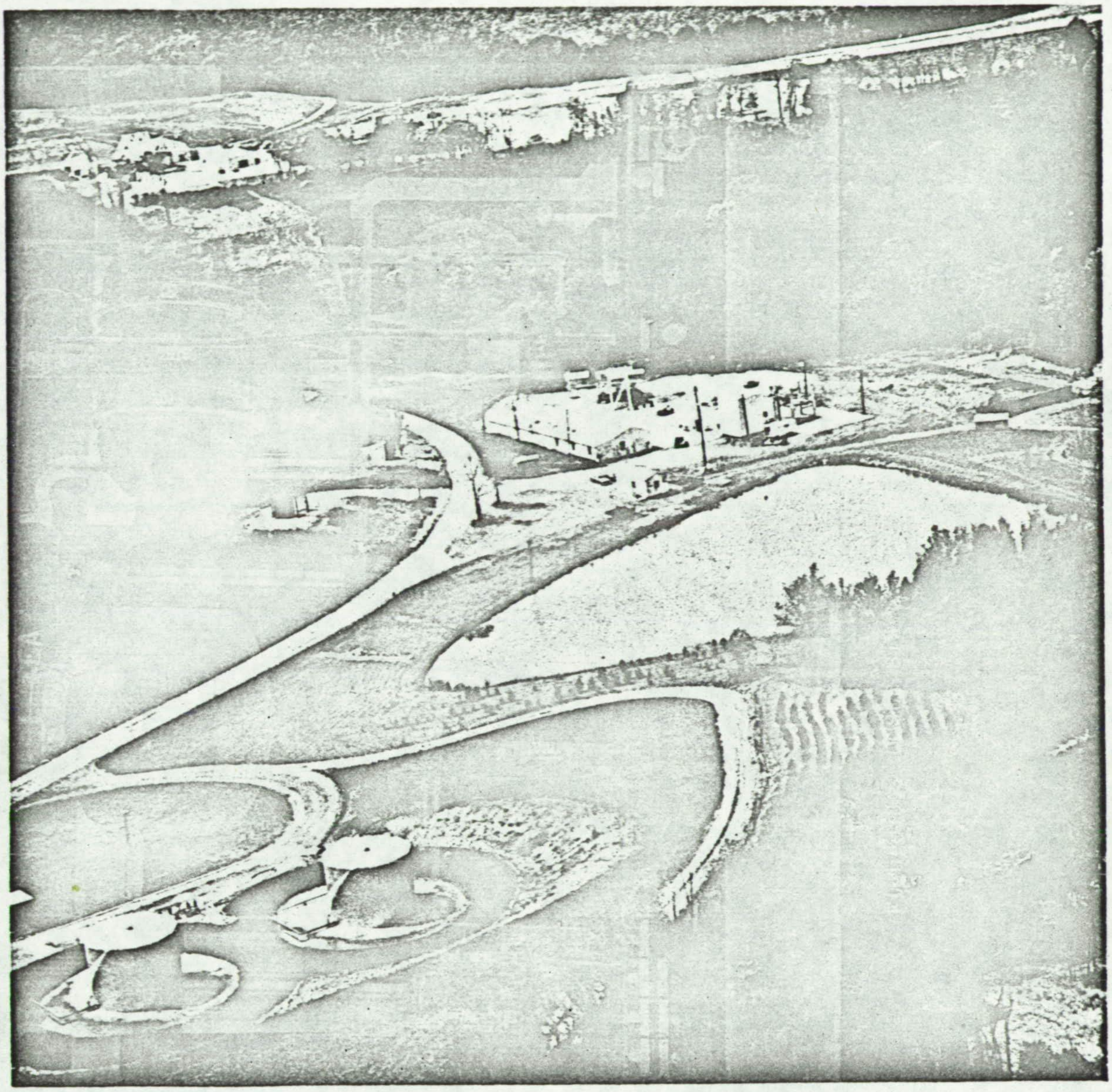

Figure 6. Peebles, Ohio Fuel Farm.

The "off engine" lubrication system provided the lube oil conditioning and oil storage facilities required for engine operation. Several modifications to the system were required to allow extended engine running. These modifications included increased lube tank capacity, oil tank heating, and a slave scavenge pump for the accessory gearbox. In addition to these, another heat exchanger was added to the system after the engine was removed from the test stand. The lube system is defined on the following drawings:

Assembly	4013180-700
Schematic	4013180-853
Engine Connections	4013180-865
Lube Tank	4013187-581
Heat Exchanger Addition	4013187-639

With the modified off-engine system, the storage capacity was 0.166 m^3 (44 gal) with tank level readout set for between 0.083 and 0.166 m^3 (22 and 44 gal). The system was regulated to deliver up to 0.003 m^3/s (50 gpm) of cooled, filtered, and deaerated oil to the engine lube pump at temperatures between 333 K (140° F) and 342 K (160° F). The slave scavenge pump for the accessory gearbox prevented the overtemperature problem by eliminating the flooding condition in the accessory gearbox encountered during initial engine testing.

The test pad was equipped to handle the following instrumentation connections:

- 200 temperature sensors, including reference thermocouples
- 384 pressure sensors, (air type) including eight vents
- 200 analog circuits (two wire-shielded pairs)
- 60 safety-monitoring circuits to engine control console
- 6 traversing probe actuator circuits

Instrumentation was connected in accordance with the Test Request and Test Request changes. Recording equipment was located at the test facility control room and also at Evendale's Instrumentation Data Center. Reference the Test Request for recorder and control room setup.

A minislipring system was used for connection of fan rotor and ring gear instrumentation. The slipring coolant console was located in the facility overhead and monitored in the control room during engine testing. Reference drawings 4013181-988 and 4013180-279 for this system.

Acoustic instrumentation was set up for initial checkout, but no acoustic testing was completed prior to the engine failure. The facility is equipped with far-field microphones and stands with provisions for near-field microphones with the use of portable stands. The mobile acoustic van was used for preliminary acoustic data recording and monitoring.

An inspection of the facility after the engine failure revealed no damage. The engine was removed from the test stand and the facility was made ready for the QCSEE OTW engine.

5.0 TEST INSTRUMENTATION

Because of the many new features incorporated in the initial testing of the UTW propulsion system, an abnormally large number of steady-state and transient pieces of instrumentation was employed. This instrumentation fell into the following general categories.

1. Operational Safety Instrumentation

   This information was displayed on the control console and either logged manually for each steady-state data point, or recorded automatically by the Automatic Data Handling (ADH) System. Several types of control console displays were employed, including panel meters, digital indicators, warning lights, and two Metrascope units. This instrumentation is listed in Tables 1-4.

2. Dynamic Instrumentation

   This information primarily included strain gages and accelerometers. Data were displayed on oscilloscopes and Schlumberger Analyzers and were continuously recorded on three magnetic tape recorders. This instrumentation is listed in Tables 5, 6, and 7.

3. Transient and Control Parameters

   These parameters were continuously recorded on four Sanborn recorders. The parameters are listed in Table 8.

4. Digital Control Data

   The digital control was designed to communicate to and from the control room via an Interconnect Unit and two control panels; an Operator's Panel on the control console, and an Engineering Panel adjacent to the console.

   The Operator's Panel, in addition to the power demand lever, incorporated digital displays of critical engine parameters as listed in Table 9.

   The Engineering Panel contained control potentiometers for manual inputs to the digital control and a digital display to read out any of 44 parameters in binary code. These parameters were also printed out on paper tape on command during each data reading.

5. Performance Instrumentation

   Internal engine pressures and temperatures from rakes, static taps and probes were recorded automatically for each data point by the ADH System. These parameters are listed in Table 10.

Table 1. Safety Instrumentation.

Item Numbers	Description	Press.	Temp.	Strain Gage	Accel	Other
006901	Fan Cowl Accel				1	
011001, 2	No. 3 Bearing Temp.		2			
011003, 4	Forward Sump Cavity	2				
011005	Aft No. 3 Bearing Support	1				
011006	HPT 1/Rev.					(1) 1/Rev.
011901, 2	No. 3 Bearing Vib.				2	
031001	Radial Drive Shaft Bearing		1			
032901, 2	AGB Vib				2	
033001-033006	Reduction Gear Bearing		6			
033007	Reduction Gear Oil Supply	1				
033008	Red. Gear Prox. Probe					Prox. Probe
033901, 2	Reduction Gear Vib				2	
070001	VSV, Stator Pot					(1) VSV
070901, 2	Compressor Aft Flng. Vib				2	
124002, 3	Plane 3 Probes	1	1			
231901	Exh. Cone Vib				1	
323001, 2	Fuel Manifold Press.	2				
323003, 4	Fuel Temperature		2			
323005	Fuel Inlet Press.	1				
323006, 7	Fuel Flow					(2) Flowmeters
323008	Fuel Manifold Temp.		1			
402001, 2	Lube Pump Disch. Press.	2				
404001, 2	Lube Scav. Disch. Press.	2				
404003, 4	Lube Scav. Disch. Temp.		2			
404005	Lube Scav. Filter Delta Press.	1				
404008, 9	Lube Supply Temp.		2			
404010	HX Water Flow					(1) Flowmeter
404011, 12	HX Water Temp.		2			
404013	Oil Level					Oil Level Sensor
405001	Hyd. Pump Disch. Press.	1				
417001	Lube Supply Filter Delta Press.	1				
650001, 2	Digital Control Temp.		2			
811001, 2	No. 1B Bearing Temp.		2			
811003, 4	Fan Rotor Cav. Press.	2				
811005	No. 1 Seal Air Press.	1				
811901, 2	No. 1 Bearing Support Vib				2	
812001, 2	No. 1 R Bearing Temp.		2			
813001, 2	No. 2 Bearing Temp.		2			
813901, 2	No. 2 Bearing Support Vib				2	
835801-835812	Fan OGV Strain Gages			12		
840801-840811	Fan Frame Strain Gages			11		
840901, 2	Fan Frame Vib				2	
845001-845008	Core Cowl Skin Temp.		8			
845013-845024	Under Cowl Cavity Temp.		12			
911001, 2	No. 5 Bearing Temp.		2			
911003	No. 5 Bearing Support Temp.		1			
911004-911009	Aft Sump Cav.	4	2			
911010, 11	No. 6 Seal Air Cav. Temp.		2			
911012	No. 6 Seal Forward Cav. Temp.		1			
911013	No. 6 Seal Fwd. Cav. Press.	1				
911014	No. 6 Seal Support Temp.		1			
911015	No. 6 Seal Delta Press.	1				
911016, 17	Bal. Cav. Press.	2				
911018, 19	Bal. Cav. Temp.		2			
911020-911025	Aft Sump Air Temp.		6			
911901, 2	No. 5 Bearing Support Vib				2	

Table 2. Control Console.

The following parameters were continuously displayed in engineering units on the control console.

Item	Parameter	Full Data Point
402001	Lube Pump Discharge	Log-ADH
404001	Scavenge Pump Discharge	Log-ADH
405001	Hydraulic Pump Discharge	Log
911016	Balance Cavity	Log
000009	Starter Air (Starts Only)	Log
033007	Reduction Gear Oil Supply	Log
811005	No. 1 Seal Air Supply	Log
911004	Balance Exhaust Cavity	Log
911010	No. 6 Seal Air Supply	Log-ADH
323005	Fuel Pump Inlet	Log
000008	PS3C	Log
000007	False PS3C	Log
---	Slipring Pressurization	---
011003	Forward Sump Pressure	ADH
---	Instrument Air	---
911015	No. 6 Seal/Aft Sump ΔP	Log-ADH
417001	Lube Supply Filter ΔP	Log
404005	Lube Scavenge Filter ΔP	Log
830000	Fan Speed	Log-ADH
230044	T5 Panel Meter	Log
050000	Core Speed	Log-ADH
404013	Lube Level	Log
323006	Main Fuel Flow	Log-ADH-SNBRN
323007/404010	Verification Fuel Flow/Water Flow	Log-ADH-SNBRN/Log
230044	T5 Digital	Log
000006	Throttle Position	Log
070001	VSV Position	Log-ADH
000001	Thrust	Log-ADH

Table 3. Control Console Panel Vibration Display.

Vibration Metrascope (20 Channel)

Fan and LPT Tracking Filters (12 Indications of Vibration)	Item	Full Data Point
Fan Frame Horizontal	840902	Log 2
Fan Frame Vertical	840901	Log 2
No. 1 Bearing Support Vertical	811901	Log 2
Reduction Gear Vertical	033901	Log 2
Accessory Gearbox Horizontal	032902	Log 2
No. 5 Bearing Support Vertical	911901	Log 2
Core Bypass Filter (6 Indications of Vibration)		
No. 5 Bearing Support Vertical	911901	Log
Accessory Gearbox Horizontal	032902	Log
Reduction Gear Vertical	033901	Log
Fan Frame Vertical	840901	Log
No. 3 Bearing Support Horizontal	011902	Log
Compressor Aft Flange Horizontal	070902	Log

The above parameters were continuously displayed on the control console immediately adjacent to the engine operator. Readout was directly in mils displacement. In addition, all of the above accelerometers are included in those continuously recorded on Tape Recorder A. Note that each of the "Fan and LPT Tracking Filter" items are each displayed twice, i.e., filtered for fan and LPT frequencies.

Table 4. Control Console Panel Temperature Display.

Temperature Metrascope (50 Channel)

Item	Parameter	Full Data Point	Item	Parameter	Full Data Point
01101	No. 3 Bearing	Log-ADH	845013	Under Cowl Cavity	Log-ADH
01102	No. 3 Bearing	---	845014	Under Cowl Cavity	Log-ADH
033001	Reduction Gear Bearing	Log-ADH	845015	Under Cowl Cavity	Log-ADH
033002	Reduction Gear Bearing	Log-ADH	845016	Under Cowl Cavity	Log-ADH
033003	Reduction Gear Bearing	Log-ADH	845017	Under Cowl Cavity	Log-ADH
033004	Reduction Gear Bearing	Log-ADH	845018	Under Cowl Cavity	Log-ADH
033005	Reduction Gear Bearing	Log-ADH	845019	Under Cowl Cavity	Log-ADH
033006	Reduction Gear Bearing	Log-ADH	845020	Under Cowl Cavity	Log-ADH
323003	Fuel Flow	---	845021	Under Cowl Cavity	Log-ADH
328008	Fuel Manifold	Log-ADH	845022	Under Cowl Cavity	Log-ADH
404003	Scavenge Pump Discharge	Log-ADH	845023	Under Cowl Cavity	Log-ADH
404009	Lube Supply Pump Inlet	Log-ADH	845024	Under Cowl Cavity	Log-ADH
404011	HX Water Inlet	Log-ADH	911001	No. 5 Bearing	Log-ADH
404012	HX Water Outlet	Log-ADH	911002	No. 5 Bearing	---
811001	No. 1 Ball Bearing	Log-ADH	911006	Bal. Exhaust Cavity	Log-ADH
811002	No. 1 Ball Bearing	---	911008	No. 6 Seal Air Supply	Log-ADH
812001	No. 1 Roller Bearing	Log-ADH	911012	No. 6 Seal Forward Cavity	Log-ADH
812002	No. 1 Roller Bearing	---	911014	No. 6 Seal Support	Log-ADH
813001	No. 2 Bearing	Log-ADH	911018	Bal. Cavity	Log-ADH
813002	No. 2 Bearing	---	911020	Forward of No. 5 Brg. Support	Log-ADH
845001	Core Cowl Skin	Log-ADH	911021	Forward of No. 5 Brg. Support	Log-ADH
845004	Core Cowl Skin	Log-ADH	911022	Aft of No. 5 Brg. Support	Log-ADH
845005	Core Cowl Skin	Log-ADH	830003	Slipring Bearing	Log
845006	Core Cowl Skin	Log-ADH	830004	Slipring Bearing	Log
845007	Core Cowl Skin	Log-ADH			
845008	Core Cowl Skin	Log-ADH			

The above parameters were continuously displayed on the control console immediately adjacent to the engine operator. Readout was directly in ° F. In addition to the continuous display, all of the above parameters were recorded on ADH each time a full data reading was taken.

Table 5. Tape Recorder A - Vibration.

All of the following were continuously recorded as well as displayed on the scopes:

Channel	Parameter	Item
1	Time Code	
2	Fan Cowl	006901
3	S/R Accel	830007
4	Fan Frame (V)	840901
5	Fan Frame (H)	840902
6	No. 1 B Bearing (V)	811901
7	No. 1 B Bearing (H)	811902
8	No. 2 Bearing (V)	813901
9	No. 2 Bearing (H)	813902
10	No. 3 Bearing (V)	011901
11	No. 3 Bearing (H)	011902
12	Reduction Gear (V)	033901
13	Reduction Gear (H)	033902
14	C/S Aft Flange (V)	070901
15	C/S Aft Flange (H)	070902
16	No. 5 Bearing (V)	911901
17	No. 5 Bearing (H)	911902
18	Exhaust Cone	231901
19	AGB (A)	032901
20	AGB (H)	032902
21	Digital Control	650901
22	Proximity Probe	033008
23	Ring Gear S/G	033801
24	Ring Gear S/G	033802
25	Fan Speed	
26	Core Speed	
27	LPT Speed	
28	Voice	

Table 6. Tape Recorder B - Fan Blade and OGV Dynamic Strain Gages.

All of the following were continuously recorded as well as displayed on the scopes:

Channel	Parameter	Item
1	Time Code	
2	Fan Blade (Dynamic Strain Gage)	830801
3	Fan Blade (Dynamic Strain Gage)	830802
4	Fan Blade (Dynamic Strain Gage)	830803
5	Fan Blade (Dynamic Strain Gage)	830804
6	Fan Blade (Dynamic Strain Gage)	830805
7	Fan Blade (Dynamic Strain Gage)	830806
8	Fan Blade (Dynamic Strain Gage)	830807
9	Fan Blade (Dynamic Strain Gage)	830808
10	Fan Blade (Dynamic Strain Gage)	830810
11	Fan Blade (Dynamic Strain Gage)	830811
12	Fan Blade (Dynamic Strain Gage)	830813
13	Fan Blade (Dynamic Strain Gage)	830814
14	Fan Blade (Dynamic Strain Gage)	830816
15	Fan Blade (Dynamic Strain Gage)	830817
16	Fan OGV (Dynamic Strain Gage)	835801
17	Fan OGV (Dynamic Strain Gage)	835802
18	Fan OGV (Dynamic Strain Gage)	835803
19	Fan OGV (Dynamic Strain Gage)	835804
20	Fan OGV (Dynamic Strain Gage)	835805
21	Fan OGV (Dynamic Strain Gage)	835807
22	Fan OGV (Dynamic Strain Gage)	835809
23	Plane 25 XPT	840108
24	Plane 25 XPT	840109
25	Fan Speed	
26	Core Speed	
27	LPT Speed	
28	Voice	

Table 7. Tape Recorder C - Rake and Fan Frame Dynamic Strain Gages.

All of the following were continuously recorded as well as displayed on the scopes:

Channel	Parameter	Item
1	Time Code	
2	Rake Strain Gage (Inlet)	800801
3	Rake Strain Gage (Inlet)	800803
4	Rake Strain Gage (Inlet)	800805
5	Rake Strain Gage (Inlet)	800807
6	Rake Strain Gage (Boundary Layer)	800809
7	Rake Strain Gage (Strut)	800811
8	Rake Strain Gage (Strut)	800812
9	Rake Strain Gage (Strut)	800813
10	Rake Strain Gage (Plane 25)	800817
11	Rake Strain Gage (Plane 25)	800821
12	Plane 25 XPT	840107
13	Light Probe 84030	840301
14	Light Probe 84030	840302
15	Fan Frame (Dynamic Strain Gage)	840801
16	Fan Frame (Dynamic Strain Gage)	840802
17	Fan Frame (Dynamic Strain Gage)	840803
18	Fan Frame (Dynamic Strain Gage)	840804
19	Fan Frame (Dynamic Strain Gage)	840805
20	Fan Frame (Dynamic Strain Gage)	840807
21	Fan Frame (Dynamic Strain Gage)	840808
22	Fan Frame (Dynamic Strain Gage)	840809
23	Far-Field Mike (60°)	
24	Far-Field Mike (120°)	
25	Fan Speed	
26	Core Speed	
27	LPT Speed	
28	Voice	

Table 8. Sanborn Recorders.

Four Sanborn recorders in the control room recorded the parameters defined below:

Sanborn Recorder A - Digital Control Parameters

Channel	Parameter	Units	Range
1	A18 Torque Motor Current	Amps	±100 MA
2	VP Torque Motor Current	Amps	±100 MA
3	Fuel Flow Torque Motor Current	Amps	±100 MA
4	A18 Actuator Stroke	Inches	- 0.247 to 4.5
5	VP LVDT Signal	Inches	- 0.247 to 4.5
6	Fuel Flow	lb/hr	0-10K
7	T41C	° F	0-3K
8	Inlet Mach Number	---	0-1.0

Sanborn Recorder B - Digital Control Parameters

Channel	Parameter	Units	Range
1	PS3/PTO	---	0-20
2	Power Demand	%	0-100
3	PLA	Degree	0-100
4	LPT Speed	rpm	0-10K
5	Core Speed	rpm	15.5K
6	Fuel Manifold Pressure	psig	0-800
7	VSV Position	Degree	-5 to 60
8	T5 (Any of 44 from Engrg. Panel)	° F	0-2000

Sanborn Recorder C - Digital Control Parameters/Strain Gages

Channel	Parameter	Units	Range
1	A18 Rod End	psig	0-3000
2	A18 Heat End	psig	0-3000
3	Fan Blade Static Strain	μ-in/in	0-3000
4	Fan Blade Temperature	° F	0-250
5	Fan Blade Static Strain	μ-in/in	0-3000
6	Fan Blade Temperature	° F	0-250
7	Fan Speed	rpm	0-4000
8	-		

Sanborn Recorder D - Fan Blade Static Strain Gages

Channel	Parameter	Units	Range
1	Fan Blade Static Strain	μ-in/in	0-3000
2	Fan Blade Temperature	° F	0-250
3	Fan Blade Static Strain	μ-in/in	0-3000
4	Fan Blade Temperature	° F	0-250
5	Fan Speed	rpm	0-4000
6	-		
7	-		
8	-		

Table 9. Digital Control.

Operator Panel on Control Console

The following parameters were continuously displayed in engineering units on the Digital Control Operator Panel on the control console directly in front of the engine operator.

Fan Speed	Fan Exhaust Nozzle Area	Thrust Parameter
Core Speed	Fan Pitch Angle	T41C
Power Demand	Inlet Mach Number	T41C

Engineering Panel (Adjacent to Control Console)

The Digital Control Engineering Panel includes a selectable digital display for any one of the variables listed below. Any one of the 44 may be read out, when selected, in a binary code. The operator of the engineering panel used equations for each of the parameters to convert them from binary code to engineering units. Each of the following were recorded by the engineering panel operator whenever an ADH reading is taken:

Thumb Wheel Switch Position	Parameter	Thumb Wheel Switch Position	Parameter
00	A18 TMC	24	MVP
01	βF TMC	25	βF1
02	WF TMC	26	βF2
03	WF	27	βF Demand (Auto Mode)
04	A18	28	A18 Demand (Auto Mode)
05	βF	29	T3
06	FMP	30	VSV Reset TMC
07	T41C	31	Mode Word
08	XM11	32	Hydraulic Pump Discharge Pressure
09	PS3/PTO	33	WF Temperature
10	Power Demand	34	βF Rate
11	PLA	35	EGT
12	N1	36	Engine Oil Inlet Temperature
13	N2	37	Scavenge Oil Temperature
14	VSV	38	Engine Oil Inlet Pressure
15	WF MCI	39	Scavenge Oil Pressure
16	βF MCI	40	T25
17	A18 MCI	41	P5
18	F.I.	42	Gearbox Interrace Bearing Temperature
19	T12	43	Horizontal Vibration
20	PTO	44	Vertical Vibration
21	P14-PTO		
22	PTO-PS11		
23	PS3		

Table 10. Engine Instrumentation Hookup - Aeroinstrumentation.

Item Numbers	Description	Press.	Temp.	Other
	Bellmouth Inlet			
005201-005240	(4) Inlet Rakes	20	20	
005254-005260	(1) Boundary Layer Rake	7		
005301-316	Wall Statics			
	Fan Bypass			
840001-840023	Bypass Duct Statics	23		
840024-840031	Plane 25 Statics	8		
840032-840036	Splitter Lip Statics	5		
840037-840042	Compressor Inlet Statics	6		
840043-840046	Plane 15 Statics	4		
840201-840230	(6) Compressor Inlet Rakes	30		
840231-840235	(6) Compressor Inlet Rakes		5	
840246-840250	(6) Compressor Inlet Rakes		5	
840256-840260	(6) Compressor Inlet Rakes		5	
840107-840109	(6) Compressor Inlet Rakes			(3) Dyn. Press.
840101-840103	(1) Cobra Probe	1	1	
	Fan OGV			
835001-835005	Island Statics	5		
835007-835008	Vane, Manifolds	2		
835010-835014	Vane, Manifolds	5		
835101-835106	Vane Probes	6	0	
	Bypass Duct			
006001-006006	Plane 15 Statics	6		
006007-006014	Wall Statics	12		
006101-006219	(7) Arc Radial Rakes	119		
006354-006358	Plane 19 Probe	1		
	Exhaust Nozzle			
230001-230040	LPT Discharge Rakes	20	20	
230041-230045	Service Strut		5	
230046-230049	Wall Statics	4		

The ADH system provided direct telephone communication of data recorded at the Peebles, Ohio Test Site to the central computer in the Instrument Data Room (IDR) at Evendale, Ohio. The data were processed, stored, and a short list of averaged and corrected parameters was printed out on the "Quick Look" monitor in the Site IV control room as an aid in tracking the engine operating conditions. The "Quick Look" parameters are listed in Table 11.

The general layout of the control room showing locations of the various displays and control panels is shown in Figure 7.

Table 11. Quick-Look Parameters.

Typewritten output available in the control room from the ADH system for each full data point taken.

Item	Parameter	Units
XNL	Physical Fan Speed	rpm
XNH	Physical HP Compressor Speed	rpm
T2AF	Fan Inlet Temperature	° F
A18	Bypass Nozzle Throat Area	in^2
Pitch	Fan Blade Angle	Degrees
PCNLR	Percent Corrected Fan Speed	%
PCNHR	Percent Corrected Core Speed	%
WFM	Main Fuel Flow	pph
FAN TORQ	Fan Torque, Calculated	ft/lb
E2AD15	Bypass Duct Inlet Efficiency	---
W2AR	Corrected Fan-Face Total Flow	pps
XM11	Inlet Throat Mach Number	---
W25R	Corrected Core Inlet Air Flow	pps
P3/P25	HP Compressor Pressure Ratio	pps
P15MW/2A	Fan Bypass Pressure Ratio	---
E25D3	HP Compressor Adiabatic Efficiency	---
P21MW/2A	Fan Hub Pressure Ratio	---
T41X	HPTR Inlet Total Temperature (T5, Energy Balance)	° R
T41XK	HPTR Inlet Total Temperature (T5, Energy Balance Corrected)	° R
FNR	Corrected Thrust	lb
SFCR	Corrected sfc	lb/hr/lb
T41C	HPTR Inlet Total Temperature (T3, P3, Wf Digital Control)	° R
E2AD21	Fan Hub Adiabatic Efficiency	---
T55	Exhaust Gas Temperature	° R

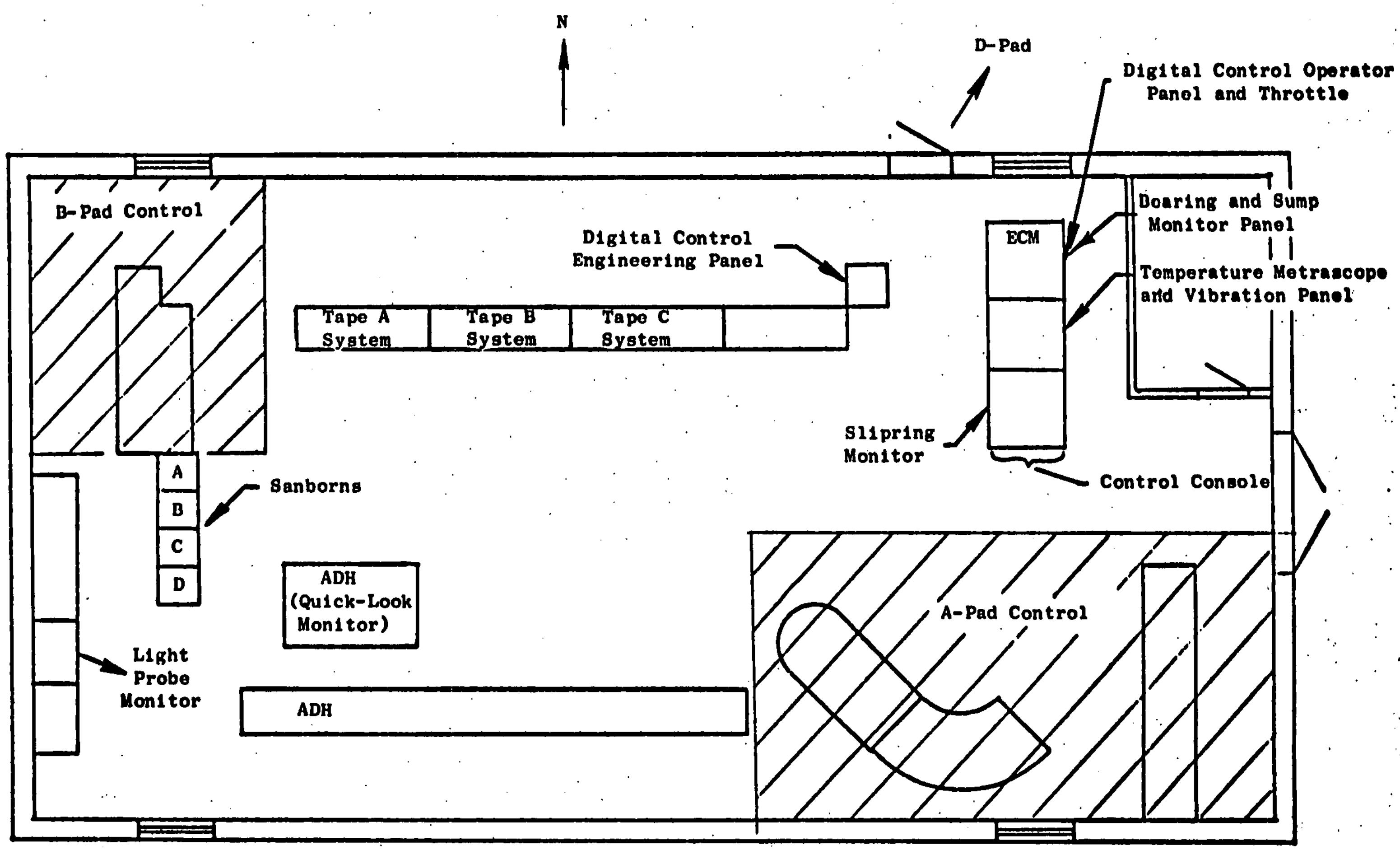

Figure 7. QCSEE UTW Mechanical Checkout Control Room Layout, Peebles Site IV.

6.0 HISTORY OF TEST

The QCSEE UTW engine, 507-001/1, arrived at Peebles Test Operation on 7/15/76. Engine installation was begun on the test stand at Site IV, Pad D. Fan and core cowling, with hardwall panels, were fitted to the engine (see Figure 8). Considerable rework and modification were required for cowling installation. The core nozzle, nozzle plug, hardwall bellmouth inlet, and instrumentation rakes were installed on the engine. The slave lube system was positioned on the test stand and serviced with Royal 899 oil. The lube-level indicator was calibrated at this time.

Calibration of the thrust measuring system was completed on 7/14/76. The load cell used was a 133,440 N (30,000 lb) cell with a three-bridge circuit. Bridge C did not calibrate properly and was not to be used for data reduction but was recorded for reference.

Calibration of the variable core compressor stator vanes, fan rotor blade angle, and fan nozzle area was completed. Variable stator position potention-meters were set on Stage 1 and Stage 3: Stage 1 open -1° 42' and closed 45° 23'; Stage 3 open -0° 44', closed +37° 28'. Fan blade angle was calibrated between -116° 07' open and +12° 47' closed. Limit switches were set at these two positions to prevent the fan actuator from running into mechanical stops. An inclinometer was used, with an adaptor, to measure blade angles at the blade tips. Fan nozzle max open with an adaptor, to measure blade angles at the blade tips. Fan nozzle max open area was 2.9 m^2 (4547 in^2); minimum closed area was 1.09 m^2 (1683 in^2). A mechanical stop was installed and set to limit the minimum closed area to 1.35 m^2 (2100 in^2). The core nozzle area was fixed 0.361 m^2 (560 in^2).

The slipring system for fan rotor instrumentation was installed and connected. Instrumentation was connected per the Test Request and Test Request changes. Recording instruments used were: Digital, S/N 60953; Sanborn recorders, S/N 539, 772, 610, and 778; and tape recorders, S/N 81004, 80637, and 64244.

On September 2, 1976, a prerun check of engine and facility was completed in preparation for initial dry and wet motoring of engine. Several hydraulic leaks were found and corrected and a small fuel leak at the engine was corrected. On the initial dry motor, a low-lube-level indication was noted due to a leak and engine "gulping." The lube system was serviced with 0.026 m^3 (7 gal) of Royal 899 oil (MIL-L-23699 Spec.).

The following is a history of test runs and significant events while the QCSEE UTW engine was on test between 9/2/76 and 12/18/76.

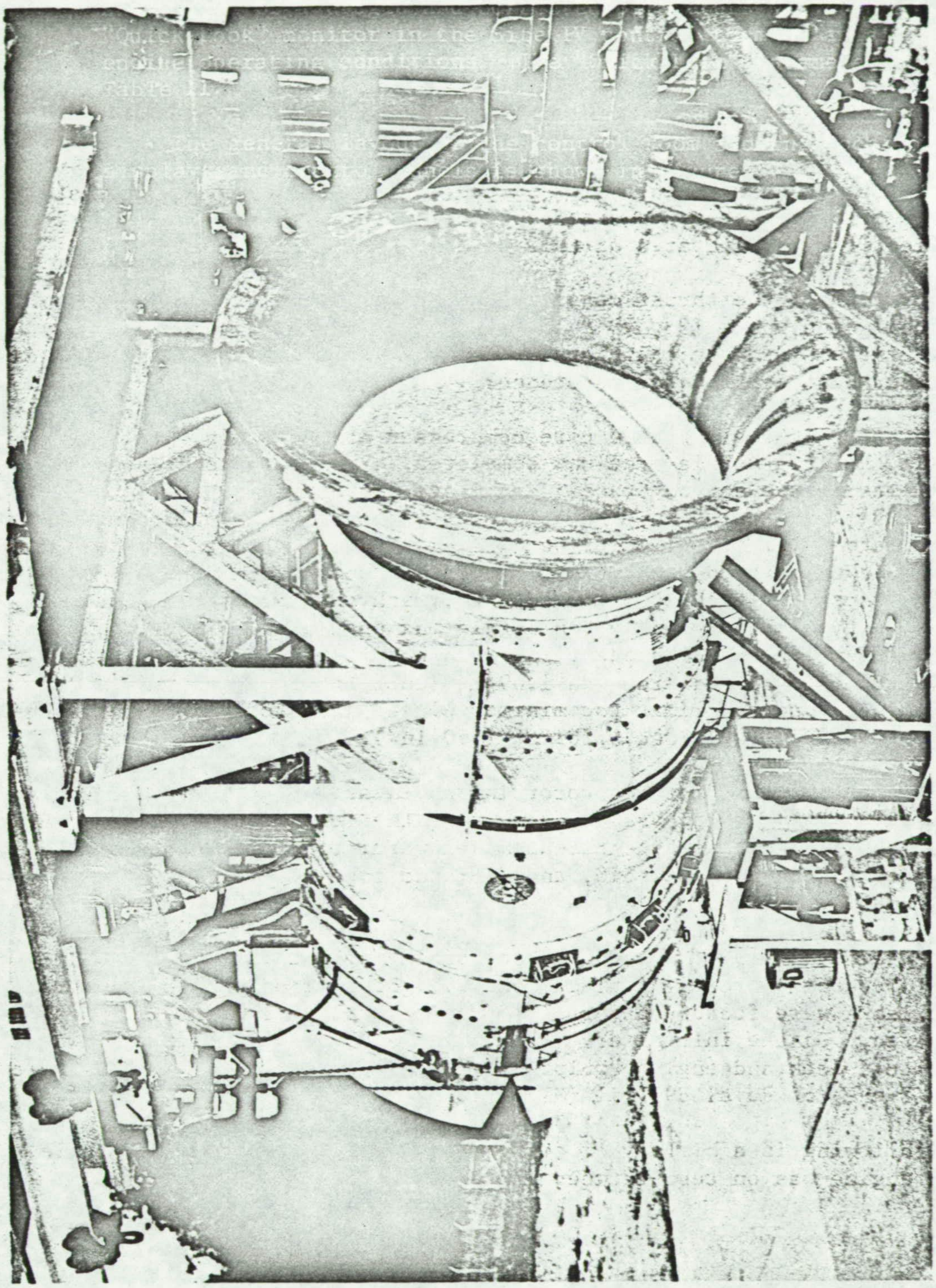

Figure 8. UTW Initial Test Configuration.

RUN: No. 1

DATE: 9/2/76

RUN TIME THIS RUN: 49 Minutes 57 Seconds

TOTAL RUN TIME: 49 Minutes 57 Seconds

ADH READING THIS RUN: No. 1 through 4

Several attempts to stabilize at idle were aborted in order to adjust the idle speed setting and to correct some safety instrumentation problems. Made a third start and established a stable idle. Idle core speed was 10,170 rpm and fan speed was 1209 rpm. Recorded several engineering panel and ADH readings. Approximately 20 minutes after reaching idle, oil vapor was seen coming out of the engine. Oil level indication was at 0.0568 m^3 (15 gal) and decreasing. The engine was shut down and a visual inspection was made. Oil was seen in the fan duct and dripping from the area between the fan rotor aft spinner and fan OGV. In an attempt to isolate the core area from the oil leak, the holes in the core cowl were plugged with bolts and washers for a diagnostic run. The origin of the oil leak from the fan rotor could not be determined; however, wet surfaces were observed around the No. 1 carbon seal and forward bearing cone. It was then decided to pressurize the carbon seal for the next start. The lube tank was serviced with 0.00757 m^3 (2 gal) of oil which brought the oil level indicator reading to 0.0492 m^3 (13 gal). The run was continued with start No. 4. Stabilized at idle and recorded engineering panel and ADH readings. Engine vibration levels were very low and speeds were stable. The digital control held fan speed, fan nozzle, and blade angle very well. Adjusted fan blade angle from nominal 0° to -3° open and accelerated from 10,160 rpm core speed to 10,700 rpm. Noted lube level continued to decrease. The engine was shut down with 0.0151 m^3 (4 gal) oil level indication remaining. This completed Run No. 1, and plans were made to clean the oil out of the fan duct, further investigate the leak, and correct instrumentation faults.

RUN: No. 2

DATE: 9/3/76

RUN TIME THIS RUN: 32 Minutes

TOTAL RUN TIME: 1 Hour 21 Minutes 57 Seconds

ADH READINGS THIS RUN: No. 5 through 9

The purpose of this run was to check out engine oil leakage in the forward sump area and determine if sumps were operating properly.

Prior to the run, the oil was cleaned off the engine and the lube tank was serviced with 0.0379 m^3 (10 gal) of oil. The control panel was changed to display No. 3 bearing cavity P_s 011005 and No. 1 seal drain pressure line P_s 811005A. Items removed were balance exhaust cavity pressure P_s 911004 and slipring pressurization.

Engine start No. 5 was aborted approximately 1 minute after lightoff due to low tube level indication. Serviced the lube tank with 0.0227 m^3 (6 gal) of Royal 899 oil. Engine start No. 6 was made and stabilized at idle, core speed 10,720 rpm, fan speed 1400 rpm, fan nozzle 1.615 m^2 (2504 in^2) and blade angle -3.2° open. Accelerated to 11,651 core rpm, 1928 fan rpm.

Lube level was monitored and recorded; level continued to decrease. When oil level indicator read 0.0265 m^3 (7 gal) at core speed of 11,651 rpm, decelerated to a core speed of 10,700 rpm and noticed the oil level had increased 0.0397 m^3 (10.5 gal). The engine was stopcocked and inspected. This completed Run No. 2. Inspection and observation results were:

- Oil leak from fan rotor/fan OGV area.
- During the run, a mist, believed to be oil, was seen in the upper pylon area.
- Several fittings in the accessory gearbox area were leaking.
- Bentley proximity probe on the reduction gear was out.

Action taken:

1. Opened core doors and fan doors and removed oil.
2. Cleaned forward sump scavenge screen and removed some small pieces of red silicone rubber.
3. Drained 2010 cc (0.5 gal) of oil from forward sump cavity.
4. Drilled two holes 180° apart in aft fan rotor spinner; hole diameter 0.15 cm (0.059 in).
5. Removed plugs from core cowling that were installed during Run No. 1.
6. Installed eductor to overboard AGB drain line from air/oil separator.
7. Added 0.030 m^3 (8 gal) of oil to lube tank.
8. Steam-cleaned core area and wiped out inlet.
9. Reset idle speed to approximately 10,900 rpm core speed.
10. Checked Bentley detector; problem appeared to be internal in sump.
11. Inspected and retorqued fittings that were leaking.

RUN: No. 3

DATE: 9/3/76

RUN TIME THIS RUN: 42 Minutes

TOTAL RUN TIME: 2 Hours 3 Minutes 18 Seconds

ADH READINGS THIS RUN: No. 10 through 15

The purpose of this run was to check out corrective steps taken and determine need for aft-sump cooling air.

The engine was fired and stabilized at idle. While monitoring the aft sump temperatures, the cooling air to this area was slowly turned off. The aft sump temperatures remained well within limits as expected. Some accels to core speed of 11,200 rpm were made to check T_3 and observe engine for additional leaks. It was noted that the mist coming out of the eductor increased slightly. While at idle, the fan pitch angle changed from -3.2° to -6.8°. The engine was shut down to investigate pitch change and blowdown instrumentation in preparation to continue mechanical checkout. Oil loss was very little compared to previous runs; however, some oil did come out of eductor and aft of the fan rotor at shutdown.

An extensive static leak investigation was conducted to determine the origin of the oil that leaks out of the area between fan rotor and fan OGV. The oil was found coming out of a hole around the No. 1 seal drain line where it enters the cavity aft of the fan in the fan frame. This hole was filled with a two-part epoxy that has the ability to adhere to a surface wet with oil. Prior to sealing around the tube, a hole was drilled into the fan frame where the tube enters the splitter lip. The tube was cut at this location and made into a drain line for the splitter-lip cavity. An eductor was connected to the drain line, external to the engine, to aid in pulling oil away from the fan rotor cavity and splitter lip. The access hole in the frame was patched and the engine washed to remove the leaked oil.

RUN: No. 4

DATE: 9/13/76

RUN TIME THIS RUN: 7 Hours 56 Minutes

TOTAL RUN TIME: 9 Hours 59 Minutes 18 Seconds

ADH READING THIS RUN: No. 16 through 48

The purpose of this run was to continue mechanical checkout including:

1. Manual N_F Mode
2. Manual A18 Mode
3. Continuation of Initial Run-in
4. Fan Performance Mapping

5. Takeoff Performance and Evaluation

6. Manual Beta Mode Checkout

High fan blade stresses were encountered during accels to a fan speed of 2200 rpm. Also, a No. 2 bearing vibration critical speed was found at a fan speed of 2025 rpm. These speeds were noted and operation in this range was to be kept at a minimum.

A small oil leak in a valve above the engine was located during the run. The engine was shut down while the valve was repaired.

Upon startup, the blade angle went to +13°. This required "jumping" of the digital control and air motoring to return the blades to nominal. Mechanical checkout continued with manual A18 mode checkout. The A18 nozzle was successfully operated over an area between 1.516 m^2 (2350 in^2) and 2.0 m^2 (3100 in^2). The area could be held within 0.003 m^2 (5 in^2). Began manual beta mode checkout. Fan speeds for initial checkout were kept under 2100 rpm. We were not able to change beta from +9° to +7° while at 2100 rpm. The engine was decelerated to a fan speed of 1800 rpm to change blade angle. It was noted that fan blade stresses were lower when the blades were in the closed positions. The manual beta mode checkout was continued along with performance mapping then slowed down to 2700 rpm. The lube level dropped to 0.0114 m^3 (3 gal) while at 2700 rpm and the engine was decelerated to idle. While at idle, the lube level recovered back to 0.045 m^3 (12 gal). A rollup to 2700 rpm was made and the engine was stabilized at a fan speed of 2600 rpm.

Engine operation was very good; vibration levels and stress were low. Continued performance mapping at this speed by varying fan exhaust nozzle area. The lube level continued to fluctuate but stayed within operating limits. After completion of performance mapping at 2600 rpm, the engine was decelerated to idle and the fan blade angle was set at -5° open for engine shutdown. The engine was shut down and secured for the night. This completed Run No. 4. Plans were to:

- Rework fan blade platforms to eliminate interference.
- Change orifice in beta hydraulic line in order to obtain more flow to beta regulator torque motors.
- Set up remote control so ejector is operable from control panel.
- Inspect turning torque on beta regulator.
- Add third lube tank to slave lube system prior to continuing mechanical checkout.

RUN:	No. 5
DATE:	9/17/76
RUN TIME THIS RUN:	48 Minutes 12 Seconds
TOTAL RUN TIME:	10 Hours 47 Minutes 30 Seconds
ADH READINGS THIS RUN:	No. 49 and 50

The purpose of this run was to continue mechanical checkout with engine operations up to 100% corrected fan speed.

It was decided to explore the operating envelope while the fan blade strain gages were still working. The engine was stabilized at idle and engine parameters reviewed. Blade angle was set at +5° closed for checkout and rollup. A moderate acceleration was made to a fan speed of 2700 rpm. Engine parameters were reviewed and found acceptable. A slow accel to 3100 rpm physical fan speed was made. After approxiamtely 30 seconds at 3100 rpm, a plume of oil started to come out of the aft end of the engine. The lube level began dropping slowly at this time. The engine was slowly decelerated to 2700 rpm, then was returned to idle and stabilized.

While at idle, the No. 2 bearing rapidly went 100° F over the limit. The engine was immediately shut down. Review of data showed no change in engine vibration to associate with the No. 2 bearing. Checkout and continuous monitoring of the No. 2 bearing thermcouple showed it was operating properly. The problem was believed due to a flooded accessary gearbox which dumped hot oil onto this bearing. A subsequent air motor on the starter revealed no problems with the No. 2 bearing nor did we see the oil plume encountered at higher speeds. The video tape was played back to try to determine the origin of the oil plume. It appeared to originate at approximately the 4:00 o'clock position, aft looking forward, in the fan duct. Plans were to borescope the No. 2 bearing area and accessory gearbox, clean oil from the flow path, and move the TV camera to the aft side of the engine for diagnostic purposes. Borescope inspections showed no problems in the sump area.

A Sanborn recorder was set up to investigate the cause of the No. 2 bearing temperature rise. The following parameters were set up for recording on the Sanborn as well as being displayed on the control panel:

- Core Speed
- No. 2 Bearing Temperature 813001
- Radial Drive Shaft Temperature 031001
- Scavenge Oil Temperature 404003
- Lube-in Pressure 402001
- Scavenge Discharge Pressure 404001

- Sump Pressure 011003
- Lube Level

RUN:	No. 6
DATE:	9/21/76
RUN TIME THIS RUN:	2 Hours 52 Minutes 38 Seconds
TOTAL RUN TIME:	13 Hours 40 Minutes 8 Seconds
ADH READINGS THIS RUN:	No. 51 through 66

The purpose of this run was to investigate the suspected accessory gearbox flooding, the oil plume, and to continue mechanical checkout.

On the initial start, the fan blade angle changed from -5° open to -46.8° open. The engine was shut down and the blades were reset to 0° position. The second start was aborted when the lube tank level indicator exceeded the full mark. A decision was made to remove the newly-added lube tank from the lube system and drain some oil from the main lube tank. It was believed that overfilling the lube tanks contributed to the flooding of the accessory gearbox and the removal of the third tank would help stabilize the lube tank levels. The engine was fired and stabilized at idle with no problems on the No. 2 bearing. Fan blade angle was set to +5° closed. Four ADH readings were recorded prior to accelerating the engine. Several slow accelerations were attempted through the critical fan speed regions but were aborted due to high fan blade stress. After several hours of running and an attempt to accelerate to 2600 rpm fan speed, the engine was shut down to correct an oil leak at the hydraulic solenoid and add oil to lube system.

The engine was fired to idle and stabilized. Fan blade angle was set to +5° closed and accel to 2600 rpm fan speed was made. An adjustment was made on the fan nozzle area, resetting it to 1.516 m^2 (2350 in^2) for some performance data readings. After completion of readings, a slow accel was made to 2715 rpm fan speed. At 2715 rpm, the lube level began to fall, and the engine was decelerated to 2600 rpm where the lube level continued to decrease. Again, the engine was decelerated to idle. At idle, the No. 2 bearing temperature began to rise and the engine was shut down. Field monitors reported the oil plume appeared again at 2715 rpm, and that the eductor connected to the splitter lip began blowing heavy vapor.

Special instrumentation that had been added to the lube system was evaluated. The data confirmed that the accessory gearbox would flood under specific operating conditions. Visual inspection of the frame and review of the video tape confirmed an oil plume originating from the lower right side through the fan duct inner wall acoustic treatment. The following action was taken in preparation for engine testing:

1. Modified slave lube system to incorporate a single 0.151 m^3 (40 gal) lube tank (Figure 9).

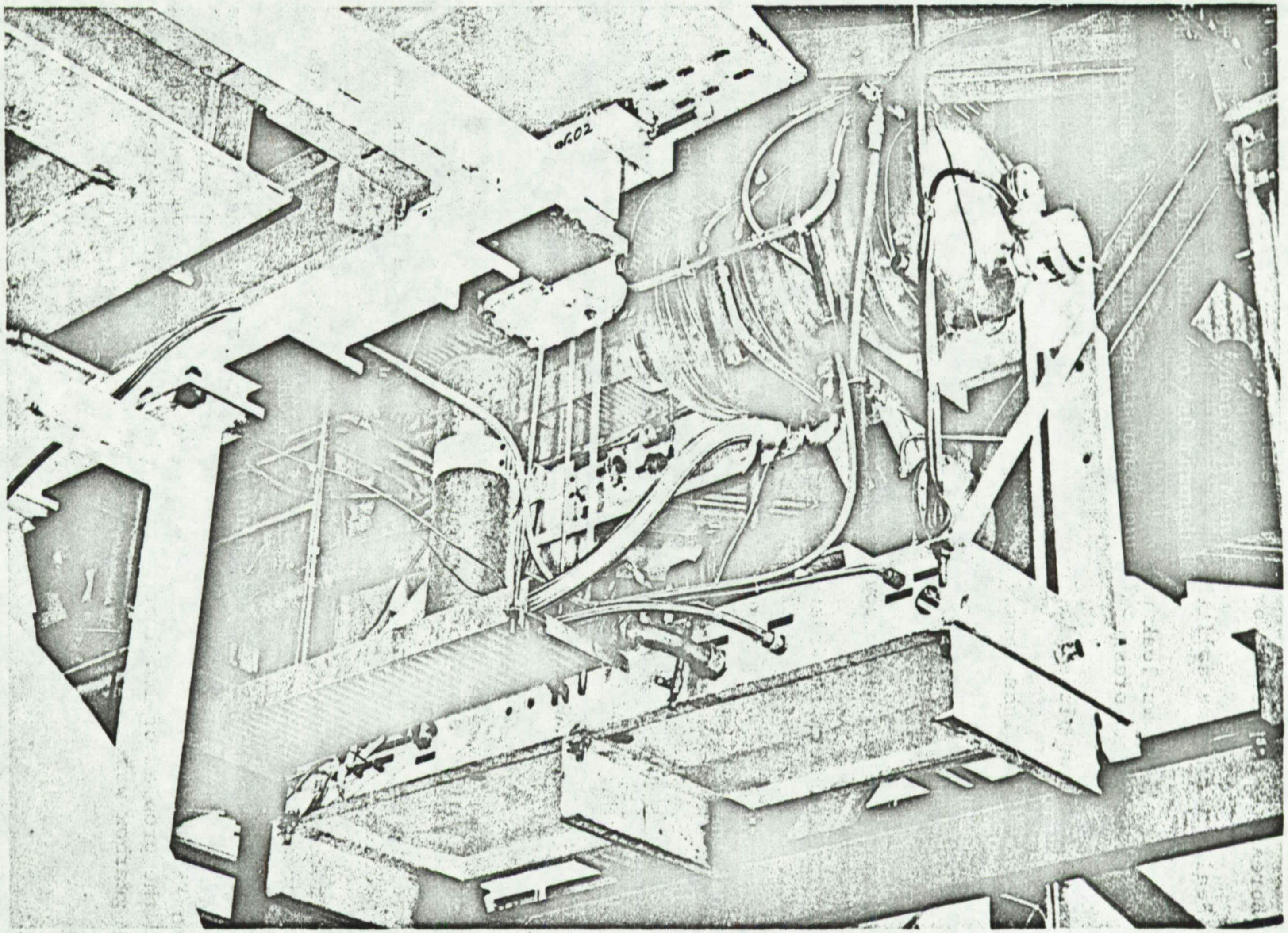

Figure 9. Modified Lube Package.

2. Helium leak-checked fan frame and determined leak paths.

3. Borescope-inspected scavenge duct in fan frame.

4. Borescope-inspected forward sump through LPT speed pickup port.

5. Sealed fan frame splitter lip and struts with "Furane" epoxy.

6. Sealed all known leak paths in fan frame verified by helium leak check and sump pressure check.

7. Reworked fan blade platforms.

8. Recalibrated lube tank.

9. Added safety and diagnostic instrumentation to scavenge pump and accessory gearbox to determine cause of flooding.

10. Lubricated fan blade dovetails with "Molykote" lubricant.

11. Set up Sanborn recorders for lube system and fan variable-pitch system diagnostic testing.

RUN:	No. 7
DATE:	10/6/76
RUN TIME THIS RUN:	1 Hour 17 Minutes
TOTAL RUN TIME:	14 Hours 57 Minutes 8 Seconds
ADH READINGS THIS RUN:	No. 67 through 72

The purpose of this run was to determine:

1. If all oil leaks were stopped.

2. If the modified slave lube system corrected the lube tank level problem.

3. If corrective action to prevent accessory gearbox flooding was successful.

Successfully fired engine and accelerated to 2850 rpm fan speed before terminating run due to rain. While at 2850 rpm, changed fan blade angle from 0° to +5° closed. Engine oil leaks were stopped and the new lube tank corrected the problem of low lube tank levels. Diagnostic testing of the accessory gearbox was continued in Run No. 8.

RUN:	No. 8
DATE:	10/8/76
RUN TIME THIS RUN:	24 Minutes 27 Seconds

TOTAL RUN TIME: 15 Hours 21 Minutes 35 Seconds

ADH READINGS THIS RUN: No. 73 through 76

The purpose of this run was to continue the diagnostic testing of the accessory gearbox.

The engine was stabilized at idle and instrumentation and recording equipment checked out. An acceleration to 2750 rpm fan speed was made after the accessory gearbox vent eductor was turned off. The engine was decelerated to idle and shut down 2 minutes after reaching the speed because of high No. 2 bearing temperature and high gearbox temperature. The problem with the gearbox was determined to be lack of scavenging. The solution was to add a scavenge port in the lower right side of the gearbox housing and connect it to a separate scavenge pump as shown in Figure 10.

RUN: No. 9

DATE: 10/13/76

RUN TIME THIS RUN: 2 Hours 20 Minutes 25 Seconds

TOTAL RUN TIME: 17 Hours 42 Minutes

ADH READINGS THIS RUN: No. 77 through 90

The purpose of this run was to continue diagnostic testing of the accessory gearbox.

The max fan speed obtained on this run was 2850 rpm at which time gearbox temperature and scavenge oil temperature reached limits. The engine was shut down and a modification was made to the new accessory gearbox scavenge line. After a successful idle leak check, the engine was shut down for the night. Testing was to resume the next day.

RUN: No. 10

DATE: 10/14/76

RUN TIME THIS RUN: 1 Hour 2 Minutes

TOTAL RUN TIME: 18 Hours 44 Minutes

ADH READINGS THIS RUN: No. 91 through 101

This run was made to complete the diagnostic test of the accessory gearbox.

The engine was run to 95% fan speed and performance data were taken at various speeds up to and including 95%. Accessory gearbox scavenge oil and housing temperatures were within acceptable limits. The engine was deceled to idle when the reduction gear bearing temperatures reached their limit of 250° F. The engine was shut down for review of data and to prepare for continuation of the mechanical checkout.

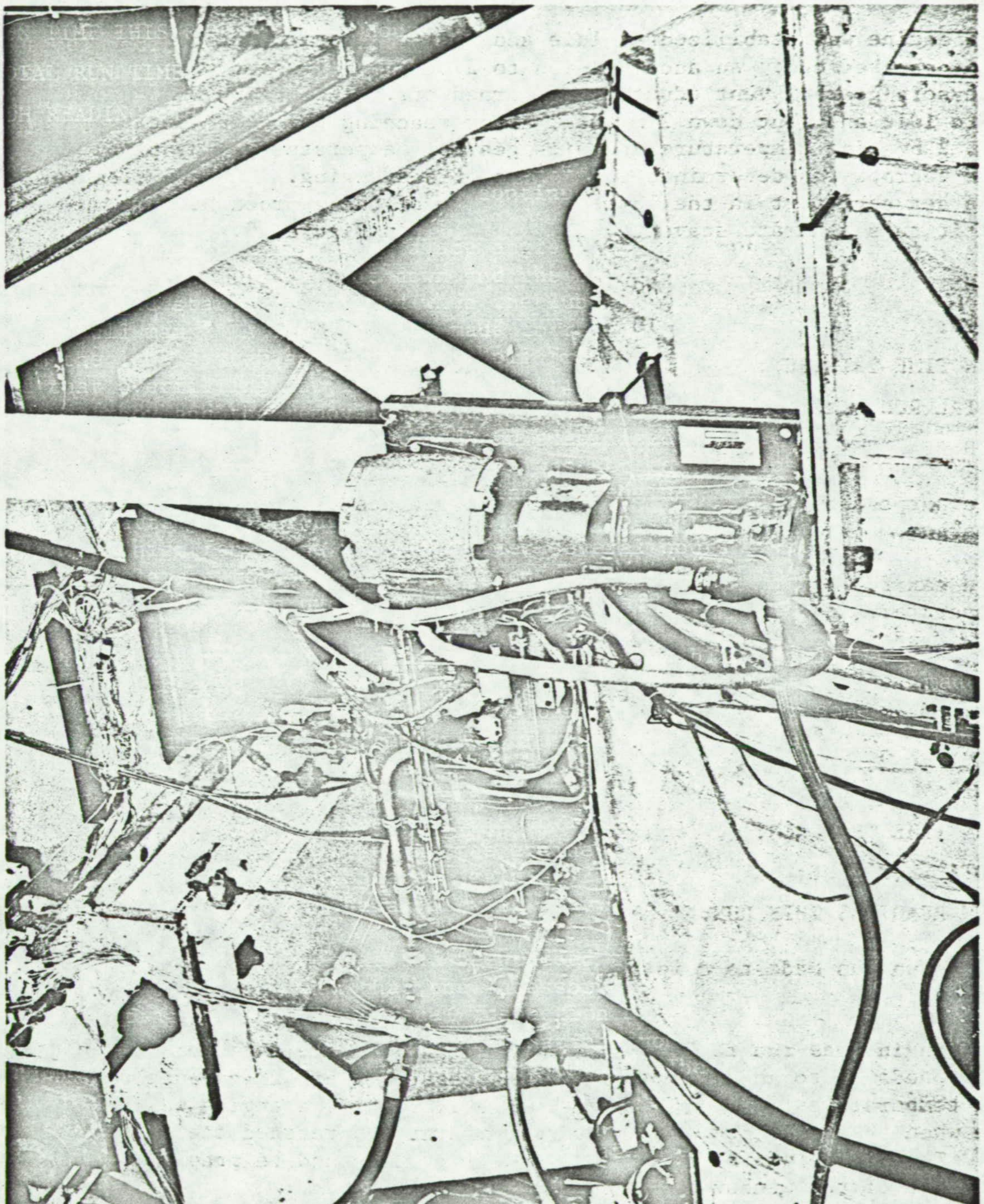

Figure 10. External AGB Scavenge Pump.

On posttest inspection of the engine, some cracks were discovered in the fiberglass inlet. The cracks required repair in order to continue testing.

RUN:	No. 11
DATE:	10/18 and 10/19/76
RUN TIME THIS RUN:	8 Hours 42 Minutes
TOTAL RUN TIME:	27 Hours 26 Minutes
ADH READINGS THIS RUN:	No. 120 through 164

The purpose of this run was to continue mechanical checkout and complete performance testing with the bellmouth inlet.

Operating techniques were developed to allow testing of this engine without additional system changes. Running time included 4 hours at or above 90% speed with 1 hour 45 minutes at 95% speed. At speeds above 90% and with fan nozzle areas between 1.71 and 1.87 m^2 (2650 and 2900 in^2), the aft under-cowl cavity temperatures would exceed the 756 K (500° F) limit. This condition was repeatable and could be rapidly alleviated by a speed decrease or closing down the fan nozzle. In order to avoid the fan blade stress problems in the speed range of 2100 to 2400 rpm, we employed moderate accels of between 1 and 2 seconds to go from 2100 rpm to 2600 rpm. Stress levels on the fan frame remained well within limits throughout the test. Engine vibrations were within limits and field balance was not required. It was noted that changes in fan blade angle caused definite changes in the overall fan 1/rev vibration amplitudes.

This test included performance mapping on five operating lines with A18 fan nozzle settings 1.35, 1.52, 1.61, 1.71 and 1.87 m^2 (2100, 2350, 2650, and 2900 in^2) at blade settings of +5°, 0°, and -5°. Aeromechanically, there were no areas of great concern although at 95% fan speed, the 6/rev response became dominant. Accels were made from 2650 rpm to 3035 rpm with $\beta = +9°$ and A18 = 1.87 m^2 (2900 in^2), at $\beta = +5°$ and A18 = 1.45 m^2 (2250 in^2) and $\beta = +5°$ and A18 = 1.87 m^2 (2900 in^2). At $\beta = -5°$ and 85% N_F while closing the A18 from 1.52 to 1.35 m^2 (2350 to 2100 in^2), the blade stress and engine vibration readout indicated what was thought to be incipient stall at A18 = 1.39 m^2 (2150 in^2). Limits were not reached due to a rapid "backoff."

The digital control continued to operate satisfactorily. Speed and A18 settings could be set and held very accurately. Most fan blade angles could be set at speed except for one movement between +9° to +5° which had to be set at 2525 rpm instead of 2715 rpm. On two occasions, the fan pitch closed from -3° to 0° without command, but was reset without difficulty. The PLA override and T41 override were successfully demonstrated.

The lube and scavenge system functioned satisfactorily. Scavenge oil and accessory gearbox housing temperatures rose gradually with increased core speed but would stabilize. Maximum accessory gearbox scavenge oil temperature was 631 K (375° F). The slave scavenge pump and the ejector were both

on during all of this test. Total oil loss for this run was 0.0076 m^3 (2.0 gal) which was due to an external leak in the accessory area.

Maximum thrust was 83,845 N (18,850 lb) at the following engine conditions: fan blade angle -5°, 95% fan speed and A18 = 1.61 m^2 (2500 in^2). This completed the mechanical checkout. The engine configuration was changed to the hardwall accelerating inlet for further testing (reference Figure 1).

During inlet installation and inspection, several hardwall panels were found to be damaged. These panels were repaired and all other panels were thoroughly inspected for damage.

An additional under cowl cooling line was added to the aft cowl cavity to alleviate the overtemperature condition existing at high power settings. The problem of fan pitch closure during shutdown was apparently overcome by bleeding hydraulic pressure between the "open" and "cruise" ports of the hydraulic motor during shutdown.

A successful idle leak check was made on November 4.

RUN:	No. 12
DATE:	11/5/76
RUN TIME THIS RUN:	7 Hours 42 Minutes
TOTAL RUN TIME:	35 Hours 8 Minutes
ADH READINGS THIS RUN:	No. 165 through 193

The purpose of this run was aeroperformance testing with the accelerating inlet. The panel configuration was hardwall except for one inlet panel which was acoustically treated. This was a replacement for a hardwall panel that was destroyed during a repair cycle.

Prior to testing, the engine was borescope inspected and the lube system serviced with 0.015 m^3 (4 gal) of oil.

On the initial fire-to-idle, the blade stresses appeared higher than seen during mechanical checkout with the bellmouth inlet. After an accel to 2750 rpm fan speed, stresses appeared to be about the same as seen during the bellmouth test at comparable wind conditions. There were no indications of any fan blade problems due to the accelerating inlet in spite of high winds of 3.6-6.7 m/s (8-15 mph) at times.

Twenty-six data points were taken which provided input for calibration of the accelerating inlet and takeoff thrust operation. The engine was operated to 97% fan speed. Maximum thrust achieved was 81,954 N (18,425 lb). Fan blade angle was varied between -7° open and +10° closed, and fan nozzle areas between 1.35 and 1.87 m^2 (2100 and 2900 $in.^2$). The ditigal control performed well throughout most of the test.

Testing was terminated when several unexplained shifts in blade beta angle occurred. The shifts occurred with blade angle at +7° closed. It would shift to +14 closed which was past the limit-switch set point. The digital control was removed and returned to Evendale for checkout. Several suspected areas were checked out and corrected as required; however, duplication of the fault was not achieved in the lab. The digital control was returned and installed on the engine for a diagnostic test. Instrumentation was added to the engine for monitoring and recording of beta torque motor currents, LVDT feedback, and hydraulic motor pressures in order to determine cause of blade angle shifts.

RUN:	No. 13
DATE:	11/11/76
RUN TIME THIS RUN:	1 Hour 40 Minutes
TOTAL RUN TIME:	36 Hours 48 Minutes
ADH READINGS THIS RUN:	No. 194 through 196

The purpose of this run was for a diagnostic test of the fan blade angle shift and continuation of aeroperformance testing. Special instrumentation was placed on two tape recorders to determine the cause of the shift. Instrumentation was:

- Beta torque motor current-interconnect unit
- Average beta F feedback-interconnect unit
- Beta F No. 1 feedback-interconnect unit
- Hydraulic motor open-pressure supply line
- Hydraulic motor closed-pressure supply line
- Power Level Angle (PLA)

Several performance readings were recorded at various power settings up to 59,000 N (12,815 lb) thrust. The unscheduled blade closure occurred under the following conditions: 2119 rpm fan, +7° closed blade angle and 1.61 m^2 (2500 in.^{2}) A18. The incident was recorded on tape as planned. The digital control was then removed and returned to Evendale for repair.

Posttest inspection after the last run revealed several cracks in the leading edge thermal shields on turbine rear frame struts. The cracks were repair welded in the field and expansion slots in the shields were partially filled with weld to prevent further cracking.

All hardwall panels were inspected for cracks and delaminations. The acoustic panels were trial-fitted and reworked as required.

All hardwall panels were reinstalled to continue testing.

RUN:	No. 14
DATE:	11/23/76
RUN TIME THIS RUN:	27 Minutes
TOTAL RUN TIME:	27 Hours 15 Minutes
ADH READINGS THIS RUN:	No. 197 and 198

The purpose of this run was to determine if the blade closure problem has been corrected.

Engine running time was limited by bad weather. However, the digital control was checked out, and the blade closure problem did not occur. Some icing in the eductor occurred during the run, causing the forward sump pressure to decrease to 7.24 N/m^2 (10.5 psia). After shutdown, the eductor was cleared of ice and the eductor control valve was changed. The valve was changed in order to have better regulation from the control room.

RUN:	No. 15
DATE:	11/29/76
RUN TIME THIS RUN:	4 Hours 44 Minutes
TOTAL RUN TIME:	41 Hours 59 Minutes
ADH READINGS THIS RUN:	No. 199 through 219

The purpose of this run was to complete the approach condition and added takeoff tests.

High crosswinds, 3.6 to 5.4 m/s (8 to 12 mph), hampered testing and required backing off certain points due to fan blade stresses. These points were repeated and the tests were successfully completed.

While running steady-state conditions at fan blade angle of +7° closed, A18 = 1.645 m^2 (2550 $in.^2$) and 2919 fan rpm, the fan blade angle closed to +14°. The engine was shut down after cooling at idle for 4 minutes and the blades set at +3° closed. Testing resumed and the +7° closed blade angle was avoided to eliminate closure problem.

RUN:	No. 16
DATE:	12/1/76
RUN TIME THIS RUN:	1 Hour 29 Minutes
TOTAL RUN TIME:	43 Hours 28 Minutes
ADH READINGS THIS RUN:	No. 220 through 223

The purpose of this run was to demonstrate engine operation and test procedures to program management personnel from NASA and GE. The run included varying fan nozzle area, fan blade angle, and fan speed.

After review of the approach and takeoff data, the decision was made to continue with the test plan and change engine configuration for the initial reverse test.

Posttest inspection revealed some delamination of two of the inlet adapter panels. The inlet adapter was removed from the engine and fitted with a set of solid hardwall panels.

Acoustic panels were installed in the accelerating inlet, fan doors, and core doors except for six panels in the fan doors at 6:00 o'clock. Due to extensive rework required to fit these six acoustic panels, the hardwall panels were reinstalled for initial reverse thrust testing. The fan duct splitter was installed and seal faces checked. Removed the fan duct rakes and the turbine discharge rakes. Traverse probes were installed per the Test Request and immersions were checked. Inlet rakes and boundary layer rake were reversed.

The digital control was removed and the A6 module reworked. After completing bench testing of the control, the unit was reinstalled on the engine.

Yarn tufts attached to nylon cord were placed in front of the engine to determine when the fan was in reverse on initial running of engine.

The engine was ready for reverse testing on 12/16/76.

RUN:	No. 17
DATE:	12/16/76
RUN TIME THIS RUN:	3 Hours 44 Minutes
TOTAL RUN TIME:	47 Hours 12 Minutes
ADH READINGS THIS RUN:	No. 224 through 233

This run was made to conduct initial reverse mode testing. A thorough review of emergency procedures and operation procedures was conducted with test monitors and technicians.

Fan reversal was initially made on the air motors of the engine. This was done in order to check out control systems and fan blade instrumentation. Maximum blade slew rate was set at 40° per second. After each blade traverse from forward-to-reverse and reverse-to-forward, an inspection of the engine; and particularly the fan rotor, was made. No problems were encountered.

The engine was fired-to-idle and checked out in the forward thrust mode with blade angles between +5° closed and -25° open. Idle core speed was adjusted to 9222 rpm and A18 set at 2.52 m^2 (3900 in.^{2}. At a fan blade angle of -25° open and a fan speed of 1400 rpm, blade stresses approached their limit. The engine was shut down in order to set blades for reverse testing. The engine was air-motored and the fan blade angle set to -105° open.

The engine was stabilized at idle in reverse thrust. Engine conditions were: core 9922 rpm, fan 1553 rpm, A18 at 2.52 m^2 (3900 $in.^2$), blade angle at -106.5° open, and thrust at -193.5 N (-435 lb).

An attempt to make a slow accel to -12,899 N (-2900 lb) thrust was aborted due to high fan blade stresses at 2200 fan rpm. A moderate accel to 2600 fan rpm was successful and all stresses were well within limits. After an ADH and panel reading were recorded, the engine was acceleled to -12,899 N (-2900 lb) thrust. Engine conditions were: core 12,200 rpm, fan 3103 rpm, A18 at 2.54 m^2 (3890 $in.^2$), blade angle at -104.9° open, and thrust -12.588 N (-2830 lb). The engine was deceled to a fan speed of 2600 rpm using the manual power-demand slide pot. A decel to idle was then made using the automatic power-demand button. Both systems operated very well.

Fan blade angle was reset to -100° open. Several attempts to accel the engine and stabilize at 2600 rpm fan speed were required because of fan frame vertical vibs reaching warning limit. The engine was stabilized at 2612 rpm after returning to idle and positioning fan beta angle to -105° open for the accel. Reset fan blade angle to -100° open and began slow accel to 3100 rpm fan speed. While accelerating, the T5 limit was rapidly approached; the accel was discontinued at 3000 rpm with T5 1526 K (1370° F). A digital control reading was recorded. While taking the reading, engine vibs and fan blade stresses exceeded limits. The engine was "chopped" to idle. All engine fan vibs were still above 0.0254 cm (10 mils) on control panel. Therefore, an emergency shutdown was made. Engine inspection revealed the lower-right fan nozzle flap had been ingested and heavily damaged the fan rotor blades as shown in Figures 11 and 12.

Postshutdown visual inspection revealed the following:

- Limited amount of small graphite shreds scattered over the pad in front of the engine.
- Lower-right (ALF) fan exhaust nozzle flap failed by "folding" closed into the fan flowpath with the flap trailing edge striking the core cowl.
- The entire flap was then sucked into the fan duct and prevented from going forward by lodging against the acoustic splitter mounting struts.
- Flap debris continued forward and severly damaged the fan blade tips.
- Fan blade damage was characterized by missing corners varying between 12.7-22.9 cm (5-9 in.) radially and 7.6-15.2 cm (3-6 in.) chordwise (i.e., triangular corners missing).
- Apparent slight and partial delamination radiated inward from the blade corner damage.

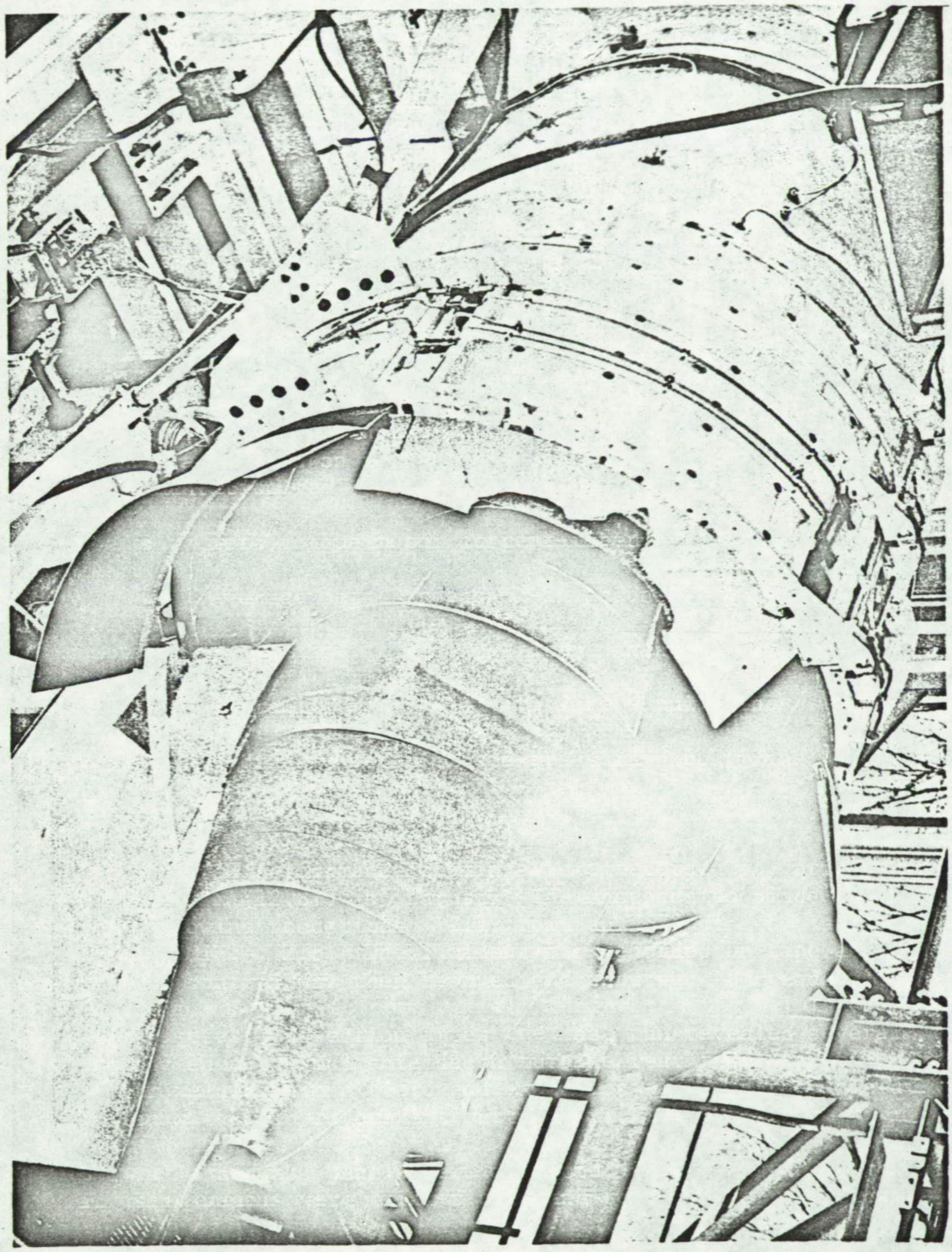

Figure 11. Three-quarter View of Engine Following Exhaust Nozzle Failure.

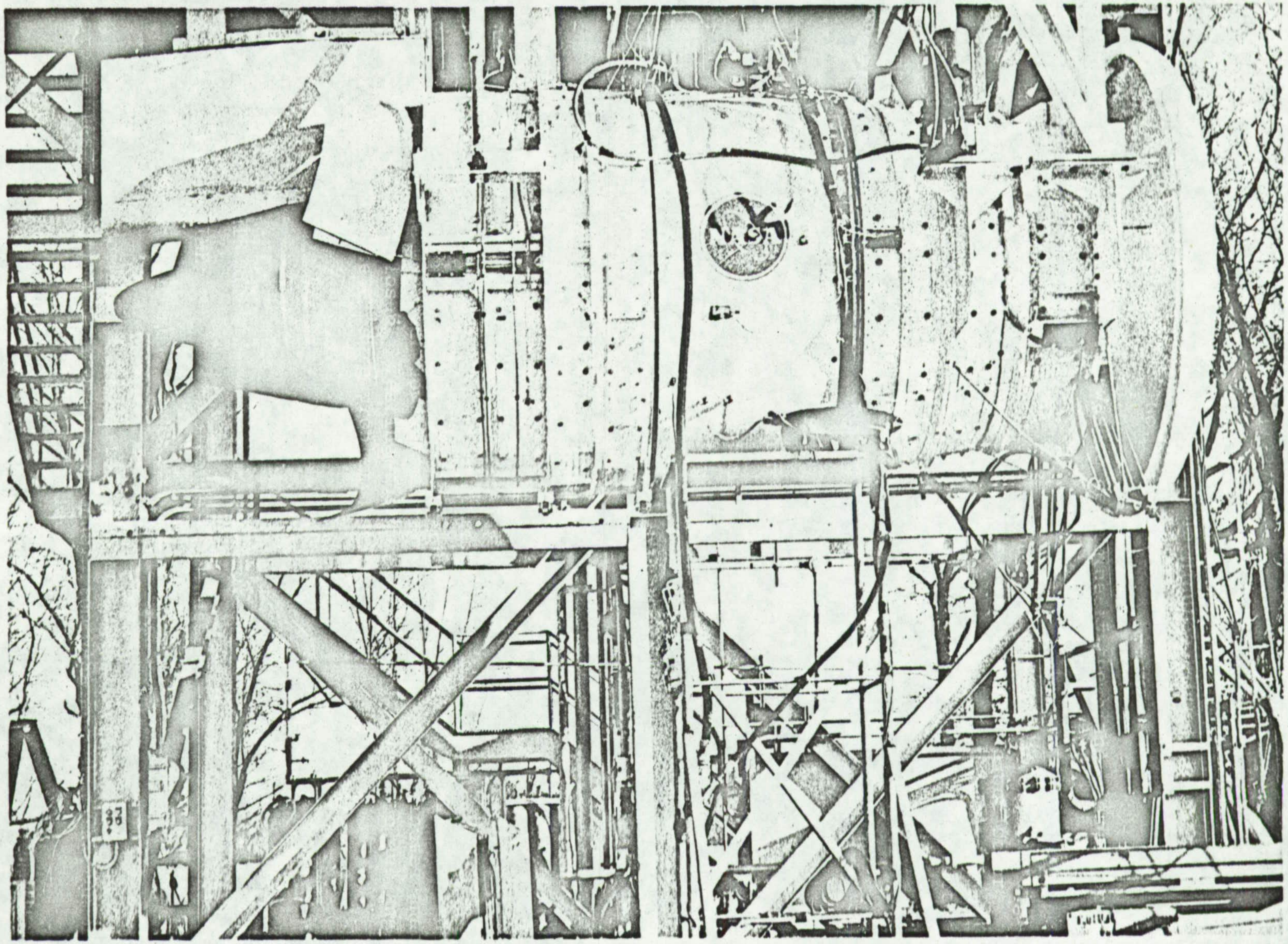

Figure 12. Side View of Engine Following Exhaust Nozzle Failure.

- Superficial fan frame damage.

- A borescope inspection of the core did not reveal any core damage.

The primary cause of the failure was an inadequate attachment of the exhaust nozzle support ring to the fan cowl, which allowed the ring to pull free and the nozzle flap to be blown inward. The primary failure is discussed in detail in Volume III of this report.

This concluded testing of the initial buildup of the QCSEE UTW engine. The engine was returned to Evendale for repair.

7.0 TEST RESULTS

Major results of testing Buildup No. 1 of the QCSEE UTW propulsion system are summarized as follows:

- Takeoff performance objectives for uninstalled thrust and sfc were met with the bellmouth inlet; and for installed thrust were met with the accelerating inlet. In both cases the T_{41} objective was exceeded by about 35 K (60° F) due to minor component variations from the predicted cycle values.

- The reverse thrust objective was not demonstrated due to premature failure of the fan exhaust nozzle support ring. However, data at off-optimum fan blade angle indicated that the engine would probably be deficient in reverse thrust. This is believed to be due to a pressure deficiency at the fan inlet associated with the acoustic splitter. The problem will be further investigated during Buildup No. 2 testing.

- Variable-pitch fan performance in the forward mode closely matched predictions over a ±5° blade angle range. Data were consistent with that from the 50.8 cm (20 in.) scale model simulator.

- The composite fan blades appear to be satisfactory for experimental engine testing, but further development/redesign is required to reduce sensitivity to crosswind and to improve fatigue margin in the first flex -2/rev crossover range.

- The main reduction gear functioned well on test and the posttest inspection indicated that all parts are suitable for further testing. Heat rejection data indicated a slightly lower than predicted gear efficiency.

- Delays in testing were caused by oil leaks from the composite frame. These leaks were stopped by coating the inside of the sump with DC94-009 fluorosilicone rubber and filling the core struts and splitter leading edge with Furane 9210 adhesive.

- In order to continue testing before the frame leaks were corrected, a shop air-powered eductor was employed to reduce sump pressures to subambient. The airflow induced in the accessory gearbox scavenge tubes interfered with proper scavenging of the accessory gearbox. This resulted in flooding the gears and overheating the lube oil; overtemperature damage was done to the gear case, gears, and seals. A lab test has since verified the cause and corrective action for the flooding problem. The problem should not recur on either the OTW or UTW engine tests.

- The digital control was used in the fully manual mode only and demonstrated accurate and stable control of fan speed, fan blade angle, and fan exhaust nozzle area. Minor problems were encountered in occasional inadvertent blade closure to the limit switch setting. This will be corrected by control modifications prior to the next buildup.

- The harmonic drive variable-pitch actuation system worked well at reduced speeds, but the blades could not be moved at maximum fan speed. This may have been due to higher-than-predicted blade twisting moments, although review of the design calculations has not revealed an error. Also, internal leakage in the hydraulic motors resulted in excessive hysteresis in positioning the blades. This was accommodated in the manual control mode by always approaching a desired blade angle from the open pitch direction. Posttest inspection indicated that the flex cable drive had been overtorqued, possibly due to inertia wrap-up in hitting the limit switch.

  It was decided that the ball spline variable-pitch actuation system would be installed for the next buildup.

- Testing was concluded prematurely by failure of the exhaust nozzle support ring during initial reverse thrust testing. This failure was due to an inadequate bolted attachment of the ring to the boiler plate fan cowl doors. Secondary damage was done to the fan blades, fan frame, and acoustic panels. The failure prevented completion of the reverse thrust testing and planned acoustic testing.

8.0 REFERENCES

1. The General Electric Company; "Quiet Clean Short-Haul Experimental Engine Under-the-Wing Final Design Report," NASA CR-134847, June 1977.

DISTRIBUTION LIST

AiResearch Division
Garret Corporation
F.B. Wallace
P.O. Box 5217
Phoenix, Arizona 85010

American Airlines
Maintenance and Engineering Center
K. Grayson
Tulsa, Oklahoma 74151

Andrews Air Force Base
Lt. Col. G. Strand
AFSC Headquarters
Washington, D.C. 20334

AVCO/Lycoming
S. Deckert
550 S. Main Street
Stratford, Connecticut 06497

The Boeing Company
H. Higgins
P.O. Box 3999
Seattle, Washington 98124

The Boeing Company
Wichita Division
D. Torkelson
Wichita, Kansas 67210

Bolt, Beranek and Newman, Inc.
R. Hayden
50 Moulton Street
Cambridge, Massachusetts 02138

Curtiss-Wright Corporation
Power Systems Division
W. Johnson
One Passaic Street
Wood Ridge, New Jersey 07075

Department of Transportation
NASA/DOT Joint Office of Noise Abatement
C. Foster
Office of Secretary
Washington, D. C. 20590

Detroit Diesel Allison Division of General Motors
F. Walters
Suite 312
333 West First Street
Dayton, Ohio 45402

Douglas Aircraft Company
L. Malthan
3855 Lakewood Boulevard
Long Beach, California 90801

Environment Protection Agency
J. Schettino
1835 "K" Street, NW
Washington, D.C. 20460

Federal Aviation Administration
Noise Abatement Division
J. Woodall
Washington, D.C. 20590

General Dynamics Convair Division
G. Nicoloff
San Diego, California 92112

Grumman Aerospace Corporation
C. Hoeltzer
South Oyster Bay Road
Bethpage, New York 11714

Hamilton Standard
Division of United Aircraft
A. Jackson
Windsor Locks, Connecticut 06096

Lockheed Aircraft Corporation
T. Higgins
Burbank, California 91503

Lockheed Georgia Company
H.S. Sweet
Marietta, Georgia 30060

NASA Installations

NASA Headquarters
N.F. Rekos
Washington, D.C. 20546

NASA-Ames Research Center
L. Roberts
Moffett Field, California 94035

NASA-Flight Research Center
D.R. Scott
Edwards, California 93523

NASA-Langley Research Center
R. Kuhn
Hampton, Virginia 23665

NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

M.A. Beheim
D.N. Bowditch
L.J. Chelko
C.C. Ciepluch
E.W. Conrad
R.J. Denington
A. Ginsburg
M.J. Hartmann
R.H. Kemp
Lewis Library
R.W. Luidens
D.L. Nored
Report Control Office
L.W. Schopen
R.W. Schroeder
M.F. Valerino

NASA/Air Force Liaison
Wright-Patterson Air Force Base
Dayton, Ohio 45433

L. Obery
C. Simpson
Col. C.E. Painter
G.K. Richey
G.P. Peterson

Pratt & Whitney Aircraft
Division of United Aircraft Corp.
J. Chew
20800 Center Ridge Road
Rocky River, Ohio 44116

Rohr Corporation
F. Hom
Box 878
Foot and H Street
Chula Vista, California 92012

Wyle Laboratories
L. Sutherland
128 Maryland Street
El Segundo, California 90245

Rockwell International
Los Angeles Division
Attn: D. Schlundt
International Airport
Los Angeles, California 90009

R. W. Williams 243/33/24701